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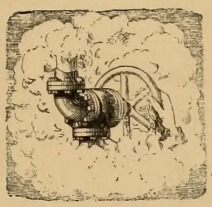

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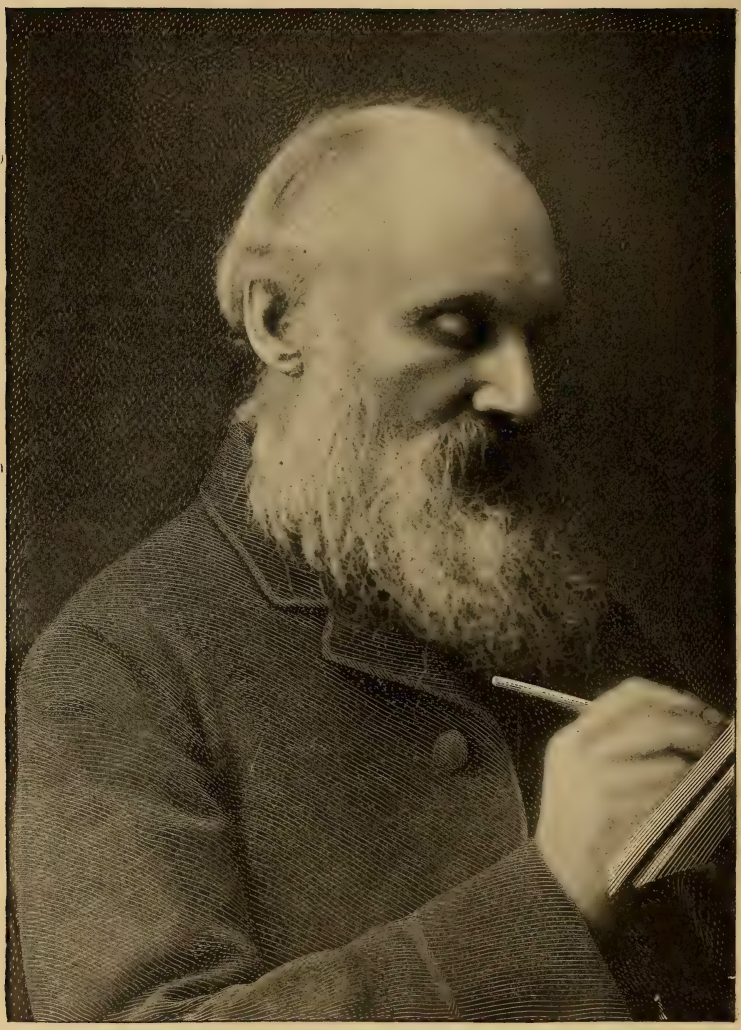

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Kelvin

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CASSIER'S MAGAZINE

VOL. XVI MAY, 1899 No. 1

LORD KELVIN

A BIOGRAPHICAL SKETCH

By J. D. Cormack, B. Sc., M. I. E. E.

AT the close of a century, unequalled in the history of the world for progress in civilisation and science, looking backward, and tracing the growth of old, the beginning and development of new sciences and the close union of theory and practice which has proved so productive of benefit to mankind, we see prominently everywhere and at every stage the work of one universal genius, — William Thomson, afterwards Sir William Thomson, and now Lord Kelvin.

For fifty-three years, as professor of natural philosophy at the University of Glasgow, he has explained in his introductory lecture that natural philosophy has for its aim the observation and classification of the operations of nature, and the discovery of its laws by inductive generalisation based upon these observations. Taking this wide view of the subject which he was called upon to teach, he has, for nearly sixty years, striven earnestly, patiently, incessantly and successfully to extend our knowledge of nature, and to apply it in the service of man. Mathematics, mechanics, sound, light, heat, thermodynamics, magnetism, electricity, elasticity, telegraphy, electrical engineering, geology, astronomy, chemistry, and navigation are all indebted to him. His genius, profound and prolific, makes

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him one of the most remarkable men in a remarkable age.

A glance at the parentage and early training of one who has secured a niche in the temple of fame cannot fail to be interesting. Lord Kelvin's father, James Thomson, a descendant of a Scottish farming family, settlers in Ulster, was born near Ballynahinch, County Down. He early displayed powers of observation and reasoning, and, as a boy, took up the study of mathematics in order to master the difficulties he had encountered in understanding the principles of dialling. Encouraged in his studies by his father, he attended a small classical and mathematical school in the neighbourhood, and there he made such progress that he was promoted to be assistant teacher. The Scottish University system provided then, even more effectively than it does now, a university education at a cost within the reach of men of very slender means, and of this James Thomson took advantage, studying at Glasgow in winter and teaching at home in summer.

After five years thus spent, during which he evinced thorough scholarship, wide sympathies and special devotion to mathematics, he was appointed headmaster of the school of arithmetic and geography at the Royal Academical Institution, Belfast, being afterwards promoted to the professorship of mathematics there. In Belfast he married, and had a family of five sons and three daughters. William was born on June 25, 1824, and was two years younger than his brother James, who, afterwards, as professor of civil engineering and mechanics, became his colleague in the University of Glasgow.

In 1832, when William was eight years old, the Thomsons removed to Glasgow. The father had been appointed to the professorship of mathematics in the university where he had been a student, and entered on duties which he continued to discharge till his death, in 1849. He is still remembered

as a man of wide culture and thorough scholarship, an enthusiastic, and eminently successful teacher, the author of many important memoirs, and of a series of mathematical text-books, unsurpassed for method of treatment and lucidity of style.

William, with his brothers and sisters, received his early education from the father. At the age of ten he went to school, and a year later entered the university with his brother James. He soon distinguished himself, gaining, among other honours, the first prizes in the junior and senior mathematical classes, and winning, in 1838, a "University Prize" for an essay on "The Figure of the Earth." Fascinated though he was by the study of mathematical science, he did not pursue it to the neglect of classics and mental philosophy. He embraced to the full the advantages of a liberal education, and to-day laments the general tendency towards narrowness in training. The study of logic he especially recommends, —"it is to language and grammar what mathematics is to common sense;" "mathematics is the etherealisation of common sense;" "more ships have been lost through bad logic than through bad seamanship."

In 1839 he went to St. Peter's College, Cambridge, graduating in 1845. Among the wranglers he was placed second, but his originality and power gained for him the highest mathematical honour,—the Smith's Prize. At Cambridge, as in Glasgow, he was noted for his wide sympathies and attainments, not in science alone, but in other fields as well. In mental and physical recreations he participated enthusiastically, and he enjoyed to the full the social, athletic, and intellectual life of an old English university. He was President of the University Musical Society, won the Colquhoun Sculls, and rowed in his college boat when second in the Cambridge races. The years spent at his "revered and loved" St. Peter's College are still affectionately remembered. A few years ago, as a token of gratitude, he presented it with an electric installation; and the Fellowship bestowed on him in his youth, resigned on his marriage, and reconferred in 1872, he values among the highest of the recognitions of his work.

From Cambridge he went to Paris, studied for a time under the famous Regnault, and continued the valuable original contributions to science which he had begun at Cambridge.

His early papers are remarkable and contain germs developed in his later work. His first published paper, written at the age of sixteen and dated Frankfort, July, 1840, Glasgow, April, 1841, appears in the *Cambridge Mathematical Journal*, May, 1841. It was a

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THE INNER COURT. OLD COLLEGE

THE PHYSICAL LABORATORY AT THE UNIVERSITY OF GLASGOW

defence and elucidation of certain fundamental theorems in Fourier's "Harmonic Analysis," the truth of which had been questioned by Kelland. This he followed up in 1842 by a paper "On the Uniform Motion of Heat in Homogenous Solid Bodies, and its Connection with the Mathematical Theory of Electricity." In it he displayed some of the spirit now recognised as characteristic of his work. Pointing out the analogy between the flow of heat in solid bodies and the theory of electric and magnetic attraction, he made use of known theorems in heat in order to obtain solutions of problems in electricity and magnetism.

His results had, as he afterwards heard, been anticipated by Green, but the beautiful method which he adopted was entirely original, and has proved a fruitful conception in electric and magnetic problems. With some difficulty he was able to unearth a copy of Green's memoir, and had it published in English in Crelle's German *Mathematical Journal*. Charmed by "Fourier's great mathematical poem," as in later years he called it, he has never wearied of proclaiming its beauties, and in 1880 he contributed a valuable compendium of the Fourier mathematics to the Encyclopædia Brittanica.

In 1846 he became attached by an additional link to Glasgow, when appointed professor of natural philosophy in his *alma mater*, in succesion to Dr. Meikleham. Six years later he married Margaret, daughter of Walter Crum, Esq., F. R. S., of Thornliebank; she died in 1870.

Although only twenty-two years of age at the time of his appointment, William Thomson had already made a reputation. He had published nearly a score of papers, chiefly on the theory of heat and static electricity, bearing the stamp of originality and promise. In reference to his candidature one of his Cambridge tutors wrote:—"He is recognised here by the most competent judges as the first man of

science of the rising generation in this country."

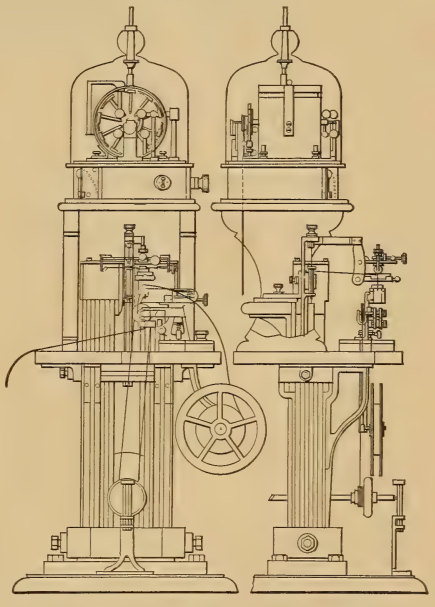
The anticipations of his teachers have been amply fulfilled, and the confidence of the University of Glasgow has been repaid by a brilliant, faithful and invaluable service of more than half a century.

His inaugural dissertation, "De Motu Caloris per Terræ Corpus," dealing with a method of finding absolute geological dates from observations of underground temperatures, was founded on a paper written in 1844, "Notes on some Points in the Theory of Heat." The further development of this subject appears in many later papers, contributed chiefly to the Royal Society of Edinburgh, and the Geological Society of Glasgow.

At the British Association meeting in 1885 he explained the value, and urged the need, of special geothermic surveys, and these have since been largely carried out. Forbes' observations on underground temperature in different strata in the Edinburgh neighbourhood gave Thomson the data necessary for estimating approximately the age of the earth. He first showed how the Fourier analysis gives a more accurate and complete reduction of the observations; he then applied it to the results of the five years' observation by Forbes, supplemented by those of thirteen additional years. In this way he obtained the factors on which he based his calculation—the average diffusivity for heat of surface rock, and the average rate of increase of temperature downwards.

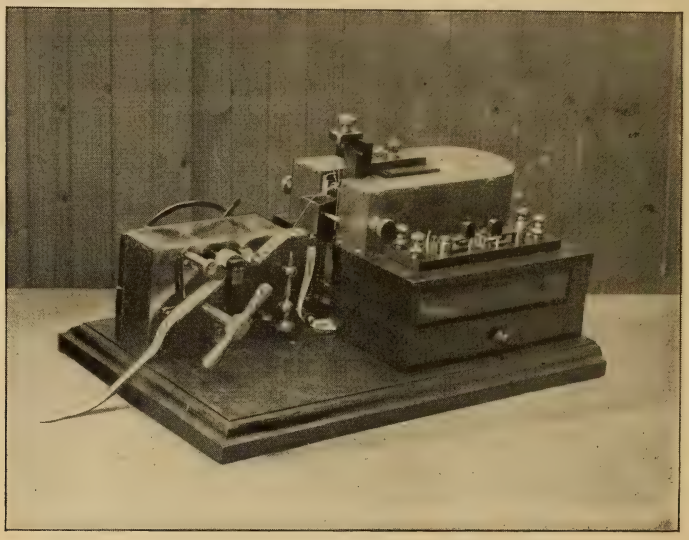
In a paper read to the Royal Society of Edinburgh in 1862, "On the Secular Cooling of the Earth," he discussed the origin of underground heat; showed that the hypothesis of chemical action and Poisson's hypothesis as to the previous journey of the earth through a hotter region of space, were both extremely improbable and incapable of explaining the present state of underground temperature, and concluded by treating the earth merely as a mass of incandescent liquid which, in cooling, has consolidated and is still cooling by radiation of its heat. The problem of finding the date of solidification, involving, as it does, a knowledge of the nature and properties of the interior as well as of the surface strata, was naturally one which did not permit of accurate solution with the insufficient data at his disposal, but after indicating the difficulties and allowing very wide limits he made an estimate. Assuming the temperature of melting rocks to be 7000° F., he showed that if the consolidation had taken place 98 million years ago, the average rate of increase of underground temperature in surface strata would be now somewhat nearly what it actually is, viz., 1° F. for every 50 feet descent.

Further, after making sufficient allowance for the uncertainty in the data and conditions, he asserted the great probability that the earth cannot have consolidated less than 20 million, or more than 400 million, years ago. This fascinating mathematical problem, which, from a consideration of the present circumstances, gives the past thermal history of a body, heated and left to cool undisturbed, is now classic and familiar to every student of mathematical physics. Its practical application to the



THE SIPHON RECORDER FOR OCEAN TELEGRAPHY

earth gave decisive time limits within which geologists and biologists must confine their evolutionary speculations. Hitherto uniformitarian geologists had indulged their imagination untrammelled by such time limits, and granted similar freedom to biologists. Now naturally stiff, it would yield, so that the tides would be imperceptible. The forces to which such a crust would be subject would assuredly break it unless it were infinitely strong. Rocks, being denser when solid than when liquid, the equilibrium of the crust would be un-



A HORIZONTAL PATTERN SIPHON RECORDER

Thomson's 100 million years is generally accepted,—a period formerly regarded as but a second in the geological day. In subsequent papers he adduced additional arguments in support of his views.

Another hypothesis, common among geologists of the period, received its death-blow in a paper delivered in 1862 to the Royal Society of Edinburgh. Thomson showed in this that it was impossible to regard the earth as a molten mass within a solid superficial crust. He found that the effect of gravitation was greater than the effect of elasticity in giving rigidity to the earth's figure, and the rigidity of the earth, as a whole, must be at least equal to the rigidity of steel,—a prediction afterwards verified by Mr. George Darwin from a consideration of the lunar fortnightly tides. If the interior were liquid, it would be subject to the tide-generating influence of the sun and moon. Unless the crust were preter-stable if placed over a liquid. But in reality a molten mass would solidify gradually by the cooling of the surface and the falling in of the cooled part towards the centre, the mass finally becoming solid on the whole, with only vesicles containing molten matter.

Other valuable papers, given to the Geological Society of Glasgow, deal with geological time, dynamics and climate, the internal condition of the earth, polar ice-caps and similar questions. His contributions to astronomical physics deal with such subjects as the mechanical energies of the solar system, the mechanical value of a cubic mile of sunlight, the origin, total amount and annual loss of sun heat, the sun's present temperature, its age, future state, present condition, and the sources of its future supply. He accepts Helmholtz's view that the sun was formed by the mutual attraction and conglomeration of meteorites, which, falling to-

gether, produced the heat by transformation of their energy, and that the supply is being continued by the further contraction of the sun and transformation of potential energy to heat.

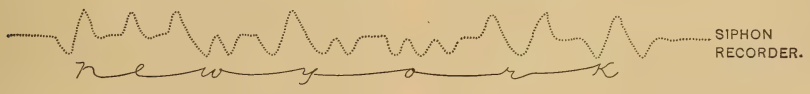
He shows that the sun's original heat and annual supply, though perhaps partly chemical, must be mainly gravitational; that, owing to its high specific heat, it must be liquid, and that its annual loss cannot be made up by any influx of intraplanetary bodies, otherwise planetary perturbations would be manifest; nor any influx of extraplanetary meteorites, for of this we would have undoubted evidence. He introduces additional information into the calculation, and agrees with Helmholtz's estimate that probably the sun's initial heat was not more than 20 million times the present annual output. In Thomson's view the sources of solar energy are gradually becoming exhausted, but we may take comfort from his estimate that there still remains of the capital five or six million times the annual draft.

His opinions on terrestrial and astronomical physics were so opposed to the geological and biological thought of the time that, in 1869, he was led into the memorable controversy with Professor Huxley, the most redoubtable debater among natural historians of his day. Views so contrary to existing hypothesis could not well be received without question, but they were gradually entertained and are now generally accepted. Huxley, referring to this spirited controversy when introducing Thomson as his successor to the presidential chair of the British Association in 1871, said of him, "Gentler knight never broke lance."

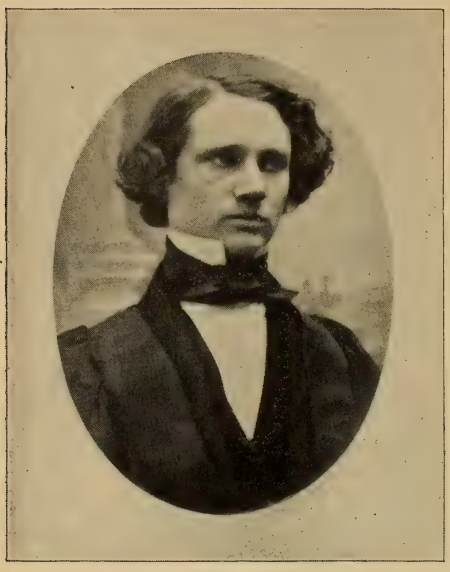
It was in telegraphy, however, that Thomson first gave evidence of that remarkable combination of mathematical ability and mechanical ingenuity which distinguishes his work. Land telegraphs had already been in use for nine years when the first short submarine telegraph cable was laid, in 1846, in Portsmouth Harbour. Its success created great excitement in scientific and commercial circles. Longer cables were successfully laid,—Dover and Calais in 1850, Holyhead and Howth in 1852, Harwich and The Hague in 1853; and before 1855 there was a network in the Mediterranean, and a cable to the Crimea, which, during its short life of a year, proved invaluable to the British War Office.

The efficiency and economy depended greatly on the "velocity of propagation" of the signals. Currents sent took some time to make their presence felt at the other end of the cable, and intermittent currents were seriously enfeebled during transmission. The difficulty demanded and received the attention of electricians. It was found from experiments on the Harwich cable that the explanation must be sought in the electrical capacity of the cable, and it seems only natural that the clue should be discovered by Faraday, whose researches on electrical capacity have obtained appropriate recognition in the association of his name with the unit in which that quantity is now measured. Faraday recognised that the wire of the cable, and the insulating covering, and the water outside form a condenser.

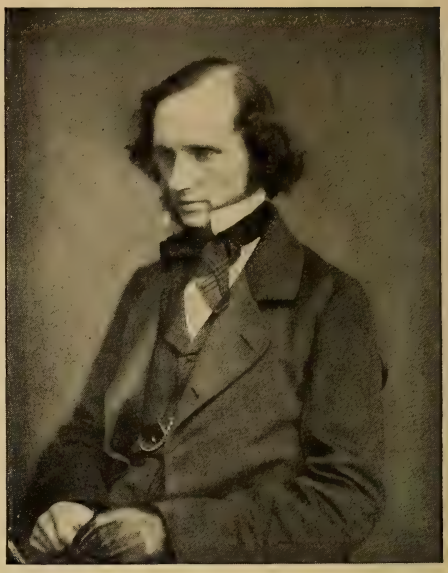
Thomson took the subject up. He found, first, a mathematical expression for the capacity, and showed how it depended on the dimensions and the insulating material used. Further, in 1854, first in a letter to Stokes, and afterwards, in the following year, in a communication to the Royal Society, he gave the investigation of the problem, leaving out of account the effect of electromagnetic induction, which he



A SIPHON RECORDER MESSAGE



IN 1846



IN 1852

PHOTO BY WHITLOCK, BIRMINGHAM.
IN 1867

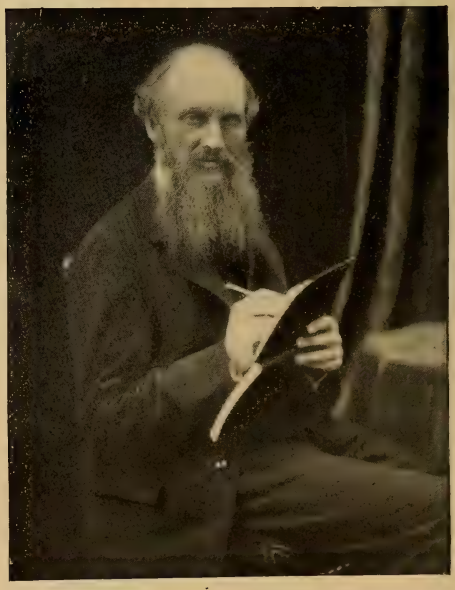


PHOTO BY JOHN FERGUS, LARGS.
IN 1880

CHARACTERISTIC PORTRAITS OF LORD KELVIN

showed to be comparatively small in a long cable. The "law of squares" was the result. An electric impulse applied to one end of a cable is not transmitted instantaneously to the other end, but gradually increases, attains a maximum, and finally falls to zero. In cables similar in material and section, but of different lengths, the time taken to experience the maximum effect, or any stated proportion of the maximum effect, at the receiving end, is proportional to the square of the length of the cable; in cables of the same length, but of different sections, it is proportional to the resistance and the capacity.

The effect of the various properties is well illustrated by the hydraulic analogy which he gave. Imagine a tube filled with a fluid transmitting an impulse from one end to the other. If the tube were rigid, and the fluid incompressible and without inertia and viscosity, the impulse would be transmitted from one end to the other instantaneously and without diminution. Make the tube elastic, or the fluid compressible, and you have the "capacity" effect; endow the fluid with inertia, and you have the "self-inductive" effect; give it viscosity, and you have the effect of the "resistance" of the cable. In long cables the inertia effect, proportional, as it is, to the length, is small compared to the capacity effect which is proportional to the square of the length.

While Thomson was busy with the theory of telegraph cables, pointing out the difficulties to be encountered in the laying and commercial working of long cables, urging the necessity for new methods of transmitting and receiving signals, explaining the scientific design of cables, and showing how to attain the most economical construction, Whitehouse, electrician to the Atlantic Telegraph Company, and others, were busy experimenting with existing cables and experimental lines, and Cyrus Field and Gisborne were discussing the financial side of the queston. Mathematicians, engineers and financiers were all bending their energies towards the task of spanning the Atlantic. Whitehouse, from a valuable series of experiments, showed that the signal took 1½ seconds for transmission through his experimental cable, 1125 miles long, and, according to the "law of squares" under similar conditions, 6 seconds would be required for the transmission of a signal from Ireland to Newfoundland, which was about twice that distance. On the whole, his results seemingly contradicted the theory, which he accordingly stoutly denied; but Thomson explained the apparent difficulties and discrepancies, and showed that, far from contradicting theory, Whitehouse's results really confirmed it.

The practical difficulties to be overcome were no sooner recognised by Thomson than he at once set himself to surmount them. Capacity and resistance were two inherent evils, but their effects could be lessened by scientific design and the use of the most suitable material. He investigated the conductivity of copper supplied by different makers as "pure," and found it to vary by as much as 50 per cent. Even specimens from the same cable gave widely different results. Further, he found that the differences were due to differences in the process of manufacture and to small amounts of impurities in the copper.

This discovery had a very important bearing on the cost and efficiency of a cable, and he succeeded in getting the directors of the Atlantic Telegraph Company to specify for the first time, and the contractors to supply, "high conductivity" copper for the extra length of cable required to replace the part lost in the two unsuccessful attempts of 1857. It was very evident that the instruments required must far surpass in delicacy existing "land" instruments, even when backed up with enormous battery power. He, therefore, turned his attention to improvements in the testing and working of electric telegraphs. His first master patent of 1858 includes keys for transmitting and the mirror galvanometer for receiving the messages. The most sensitive receiver previously used was a galvanometer constructed on Weber's principle,—a

ON BOARD LORD KELVIN'S YACHT, THE "LALLA ROOKH"

magnetised steel disc with a polished surface suspended by a long silk fibre in the centre of a coil of wire, the deflections being read by means of a telescope and scale.

The well-known Thomson mirror galvanometer surpassed its immediate predecessor even more than the modern bicycle excels the old velocipede or boneshaker. The heavy steel disc was replaced by one or more small magnets of fine flat steel, fixed to the back of a tiny circular mirror of plain or concave silvered glass. The whole system weighed only about half a grain, and was easily suspended by a single silk fibre, which could be made very short without manifesting any appreciable torsion effects. The mirror and magnets were suspended inside a horizontal brass tube only slightly larger in diameter; glass plates were screwed so close behind and in front of the mirror as to inclose it, with just sufficient clearance, in a small chamber; thus "air damping" was introduced, which brought its motions quickly to rest.

The tube was placed inside a coil which surrounded it closely, and any deflection of the mirror, produced by a current passing round the coil, was detected by means of a beam of light falling from a lamp on to the mirror and thence deflected on to a scale. For use on board ship the mirror, to prevent swinging, was suspended, top and bottom, by a stretched silk fibre, while to get rid of the disturbing influence of the ship's magnetism or moving masses of iron, the instrument was screened by a soft iron case. Its wonderful sensitiveness, accuracy and stability permitted it to be used on board ship for even the most delicate tests. It has been proved capable of detecting a signal sent across the Atlantic by a miniature battery consisting of a thimble, a needle and some salt water.

The year 1858 saw the Atlantic Telegraph Company prepared to renew their efforts, better equipped and possessed of the experience gained from the two failures of the previous year. At the request of his brother directors, Thomson took upon himself the duties of electrician on board H. M. S. *Agamemnon*, which had been placed at the disposal of the company. The *Niagara* was lent by the United States govern-

ment, and these two ships successfully established communication between Ireland and Newfoundland.

On August 6 Thomson's instruments delivered the first message and proved the commercial feasibility of an Atlantic cable. When other instruments failed to speak, the mirror galvanometer gave 2½ words per minute, even with defective transmitting arrangements. Unfortunately the cable, hurriedly constructed, seriously impaired during enforced delay, and damaged by the strains of coiling and uncoiling, gradually gave way and failed, but in its short life of a fortnight it succeeded in delivering 400 messages. The electricians and engineers, having tasted the sweets of success, were rendered more confident, the promoters still remained sanguine, but the shareholders declined to risk more money on the scheme; and in an enterprise of this magnitude complete success can be obtained only when sufficient capital supports sufficient science.

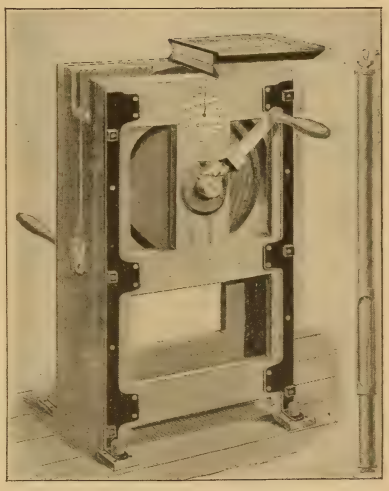
The last word spoken,—"Forward," —was a word of good omen. For a time the scheme lay dormant, but the engineers were busy. Thomson continued his mathematical and experimental investigations and still further improved the instruments. In 1865 another attempt was made to lay a new cable, constructed on improved and scientific principles, but an unfortunate accident led to its breakage. Success, however, finally attended the labours which had been pursued with unshaken faith and dauntless energy.

On July 15, 1866, the *Great Eastern* permanently established the communication for which they had so long striven, and the triumph was crowned by the recovery and completion of the cable lost in 1865. We may well apply to this great achievement the words Thomson spoke from the presidential chair of the Royal Society in 1893:—

"Tribulation, not undisturbed progress, gives life and soul, and leads to success where success can be reached in the struggle for natural knowledge."

Professor Thomson's great share in the final triumph was suitably recognised when, on the return of the expedition, he received, with several of the other heroes, the honour of knighthood. Some remarks he made at a banquet given in their honour by the Lord Mayor of London are worthy of quotation as illustrating what has been a guiding principle in his work:—

"Unless men of science pursue their studies out of a pure love of knowledge or from an abstract desire to become acquainted with the laws of nature, they will seldom carry on their labours with success; but, at the same time, no greater reward could crown their investigations than when, as in the case of electric telegraphy, they are the means of conferring a practical service on mankind, the value and importance of which are admitted on all hands.



THE NAVIGATIONAL SOUNDING MACHINE AND DEPTH RECORDER

. . . My only object in these remarks is to point out that science, to be true to itself, must be followed for its own sake, and that all the most important services it has rendered to mankind have been the result of arduous investigations, carried on by men animated with the hope of no other reward than that which awaits every sincere and industrious student of nature."

The growing prosperity of the cable demanded improvements in the instru-

ments. In conjunction with Varley and Fleeming Jenkin, various sending instruments were patented, and in 1867 Thomson invented his graphic receiver, the siphon recorder, which, since 1870, has been employed on all cables except those very few on which the mirror galvanometer still survives. In this marvellously delicate instrument the relation between the coil and magnet of an ordinary galvanometer is reversed, and a new principle is thus introduced which has since been utilised in the class of galvanometers known as D'Arsonval's.

The current which passes through the cable is led into a rectangular coil suspended between the poles of a powerful magnet. An electromagnet was used at first, but this has been superseded by a permanent magnet. The motions of the coil are communicated to a very fine capillary glass siphon, of which the shorter leg dips into the ink reservoir, while the longer acts as a pen.

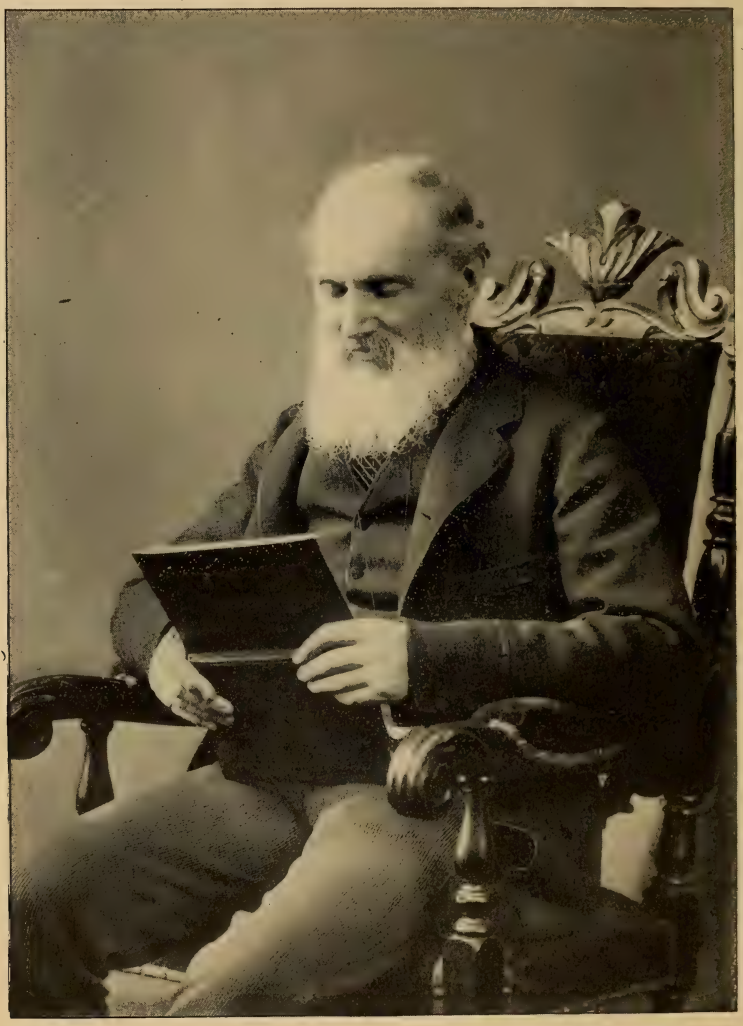


PHOTO BY MOFFAT, EDINBURGH.

LORD KELVIN IN 1886

The paper is a tape, carried by clockwork over a brass table close to the pen, but avoiding contact and friction with it. The ink is electrified by means of a small clockwork-driven induction machine, or the siphon is caused to vibrate rapidly by mechanism, and very minute drops of ink are shot on to the passing paper. As in the mirror galvanometer, the Morse code of signals is used, excursions of the coil to one side or other corresponding to dots or dashes, and the message thus appears on the tape as a wavy line which is easily read. The speed of signalling depends on the length and construction of the cable and the expertness of the operator. On a short line as many as 135 words per minute can be received, but on a long cable 20 to 30 are the average.

After 1866 Thomson was adviser to a number of other cable companies, and his annual six months' freedom from professional duties permitted him to take part in many more expeditions. On one of these, detained a fortnight in Funchal Bay on the way to South America, in 1873, he met Frances Anna, daughter of C. R. Blandy, Esq., of Madeira, whom he married in 1874.

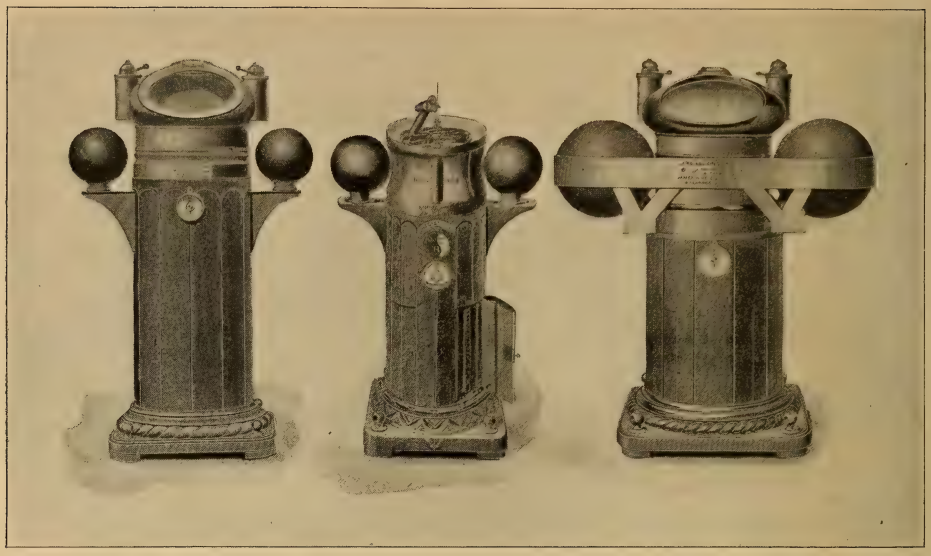
Nothing better exemplifies the intense interest Thomson took in everything than his connection with the science of navigation. An early association with nautical matters was revealed in a speech delivered by him at the unveiling at Glasgow University of a memorial bust to a companion.

"My earliest recollections of Lord Sandford," he said, "are not of his brilliant career as a student in the universities of Glasgow and Oxford, but as a boy of my own age, playing on the college green, making ships and sailing hem in the Molendinar Burn, now flowing under the ground, not like a modern terrestrial river at all, but rather like another river known in the classics. Black as Styx now, it was black enough then when Frank Sandford and I used to make docks on its banks, to moor our ships and bring them into the harbour, and when we used to fall into the muddy stream itself. These were bright and happy days in the old college and the old college green of Glasgow, full of memories to myself, too touching for me to speak of now; they are among the most treasured and valued possessions of my memory."

His telegraphic experiences seem to have whetted his appetite for the sea. For nearly 20 years from 1870 he spent most of his vacations on his yacht, the *Lalla Rookh*, a schooner of 126 tons, sometimes cable testing, sometimes on pleasure cruises. Lady Kelvin also is an enthusiastic sailor, and their honeymoon was spent on board, in a twelve-days voyage from Madeira to Cowes.

It is little wonder that the science and practice of navigation soon benefited by his fondness for the sea. In 1872 he introduced a great improvement in the apparatus required for taking deep-sea soundings. He showed the great advantages to be derived by using, instead of hemp rope, steel pianoforte wire, which combined small size, lightness and strength, weighing only about 1½ pounds per 100 fathoms, and having a tensile strength of 240 pounds. In deep-sea soundings of from 2000 to 3000 fathoms, the operation could be performed by three or four men instead of a ship's crew or a donkey engine; a weight of 34 pounds was sufficient for a sinker, and was brought back with the wire recovered, instead of a weight of two or three hundred pounds, left at the bottom; and for navigational purposes it permitted, what had not been previously even dreamed of,—flying soundings in 100 fathoms from a ship running at 16 knots. The method and apparatus devised were originally used in the laying of the Brazilian cable and proved most valuable.

The depth recorder is a useful addition. It consists of a cylinder into which a piston is gradually pushed by the water pressure against the action of a spiral spring. The final position of the piston, and, hence, the depth, is shown by a small index which is carried along a scale. Sometimes it is found convenient to use a chemical recorder. A long, fine glass tube, closed at one end, is coated inside with orange-colored chromate of silver, and the depth



SOME TYPES OF LORD KELVIN'S COMPASSES

is ascertained from the compression of the air, indicated by the chromate turning white throughout the portion of the tube into which the sea water has forced its way.

The mariner's compass next claimed his attention. In 1874 the first part of an article on "The Mariner's Compass" appeared in *Good Words*,—"To be continued,"—but not until 1879 was the second part printed. In writing it and considering the dynamics of the problem, Thomson saw how vastly the compass might be improved, and could not bring himself to describe the then existing compass when he saw how great a change was necessary, and felt that it would soon be superseded. The new compass was patented in 1876. As its design was completely at variance with prevalent practice, it is scarcely to be wondered that navigators,—proverbially conservative in everything relating to their art,—refused a welcome to an innovation based on scientific reasoning which failed to find favour in the eyes of the Astronomer Royal of the day.

THE IMPROVED COMPASS CARD

Slowly and surely, however, its merits became recognised. In 1889 Sir William Thomson's 10-inch standard compass was finally adopted by the British Admiralty, and now no ship of worth is without one or more of the numerous patterns of his compass. Since 1840 the Admiralty compass had a card 7½ inches in diameter, but cards up to 15 inches were used in merchant ships, as they were found to be steadier at sea. It had generally been considered that the magnet, or magnets, ought to be of great magnetic moment so that the directive influence of the earth's magnetism might be greater; but if the moment was great, the period of vibration of the card was small, and unsteadiness

was the result. The period was lengthened by adding weights in some manner, and thus steadiness was gained at the expense of friction at the point on which the card was supported. More drastic measures were occasionally employed to make it less lively, and the methods practised included filling the cup with dust and blunting the point! Thomson showed, however, that short magnets of small magnetic moment were desirable, not only because they allowed the possibility of a long vibration period with a light card and consequent diminution of friction, but also because they permitted the use of steel magnets and soft iron masses so disposed as to correct completely all the various errors due to the magnetic influence of the ship. This last quality was rendered all the more desirable owing to the more extensive use of iron in shipbuilding.

The problem then was, to construct a card sufficiently rigid, large, and light, with magnets short and of small moment, yet strong enough to give a controlling force sufficient to make the friction inappreciable ; and the solution is a wonderful example of delicate engineering. In the centre is a little inverted sapphire cup borne on a supporting iridium point and carrying a small aluminium disc. This disc forms the hub to which the light aluminium rim, 10 inches in diameter, is connected by spokes of silk threads. The card is reduced to a ring of thin paper fixed to the rim and the threads, and the evil effects of warping are very simply avoided by slitting the paper-ring at intervals. The magnet system of eight small needles, from 2½ to 3½ inches long, is constructed like a rope ladder and slung by silk fibres to the spokes. Compared with the old card, the weight is about one-seventeenth,—170 grains instead of 6 ounces; the magnetic moment is one-thirteenth, and the period of vibration is twice as great, being 42 seconds. The card is only one of the improvements, and subsequent patents deal with various accessories and methods for adjustment and correction.

Sumner's method for finding the position of a ship at sea found in Thomson a very warm advocate. Its utility was obvious, but it was not widely known, and the calculations to be performed, simple though they were, had still further to be shortened before there was any hope of the method becoming generally used. In 1876 he published a complete set of tables by means of which the arithmetical operations were so much shortened that they required neither more time nor skill than the methods commonly practised. So greatly has Kelvin contributed to the safety of navigation that he is regarded by appreciative mariners as an incarnation of the "cherub that watches over poor Jack."

The concluding part of this sketch will appear in the June number.

A BOER FAMILY "TREKKING"

SOUTH AFRICAN RAILWAY DEVELOPMENT

By Theodore Reunert

IT is nearly forty years since a commencement was made to build railways in South Africa, the first sod of the Cape Town-Wellington line having been turned so long ago as the year 1859, and about the same time a short line was opened from the town of Durban to the harbour at the Point. The condition of the country, however, did not warrant any active prosecution of the works, and it was not until after the discovery of the dry diggings at Kimberley had brought up the export of diamonds to over a million sterling per annum that in 1872 (memorable, also, as the year in which responsible government was proclaimed) the Cape Parliament authorised the purchase of the 60 miles of railway at that time working in the colony and the construction of other lines.

At that time, as set forth by the writer in a presidential address before the South African Association of Engineers and Architects, the journey to Kimberley from Cape Town took about seventeen days, by rail to Wellington, and thence by private waggon; now it takes thirty-six hours. The total number of passengers conveyed over the Wellington and Wynberg lines in 1873 was 436,512, and the tonnage of goods 66,328. In 1897 the passengers on Cape lines numbered 9,223,676½, and the tonnage 1,340,414.

It has probably been forgotten what a fight took place thirty years ago over the question of railway extension. The town of Worcester sent in five petitions against having the line extended to that place, and a great battle was fought over the question of gauges. Some were in favour of light tramways, 2 feet or at the most 2 feet 6-inch gauge, for animal traction, as, they argued, the traffic of an agricultural country, consisting mostly of light goods, such as wool and grain, did not justify the use of steam. It has, also, almost been forgotten that the original line to Wellington was built on the standard English gauge, viz., 4 feet 8½ inches, and but for the subsequent change to 3 feet 6 inches, the railways of South Africa would most likely to-day have all been on the broader gauge.

It is, further, a matter of history that though the success of the Diamond Fields alone enabled the railways to be extended, the routes were certainly not chosen with any regard to the interests of the fields, or indeed of the colony at large, as otherwise a single trunk line would have been pushed forward and completed within a few years. But instead of this, four separate lines of rail-

way were started to compete with one another, with the result that for many years they did not pay interest on capital, and it was not until the end of 1885 that the railway actually reached Kimberley, by which date about 1600 miles had been built, though the distance from Kimberley to Port Elizabeth, the nearest harbour, is only 485 miles.

Then a wonderful thing happened to justify this lavish expenditure on railway construction that might seriously have crippled the finances of the colony. The Witwatersrand Gold Fields were discovered in 1886, and three at least of the lines to the north began to reap the benefit of the increased traffic. The fourth line, which had been completed to Graaff-Reinet as early as 1879, was, for several years, the most direct route to the Diamond Fields, but the junction of the Cape Town and Port Elizabeth lines at De Aar, opened March, 1884, left the Graaff-Reinet and East London lines out of the running, as far as the Diamond Fields trade was concerned, and it was not until March of last year that the recent extension of the Graaff-Reinet line was opened to Middelburg Road, re-named Rosmead Junction, on the main Port Elizabeth line. With the opening up of the Transvaal Gold Fields an entire re-arrangement of the railway systems took place. Kimberley, which for fifteen years had been the centre of attraction, was replaced by Johannesburg. The opportunity offered the Cape of extending the Kimberley line straight on to Johannesburg was, however, let slip, and the competition from the eastern ports of Delagoa Bay and Durban at once came into play. On the principle that half a loaf is better than no bread, the Cape then arranged with the Free State to build the lines through that territory, and also advanced the money for the connecting link between the Vaal River and Johannesburg to Pretoria. The first through train from the Cape ports arrived here in September, 1892, and for the next three or four years the Cape got the lion's share of the Transvaal traffic. Meanwhile, the Netherlands Railway Company, which had commenced with the modest Rand Tram of 35 miles from the Boksburg collieries to Krugersdorp, was building the eastern line from the Portuguese border, via Middelburg to Pretoria, and subsequently the south-eastern line to the Natal border and the south-western line to Klerksdorp. The first through train from Delagoa Bay arrived at Johannes-

PHOTO BY BARNETT

PARK STATION AT JOHANNESBURG

THE WHARF AT DURBAN

PHOTO BY BARNETT

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burg in November, 1894, and from Natal in December, 1895.

But it is not merely the rise of Kimberley and Johannesburg which has led to the recent rapid railway development of the country. Thirty years ago the northern boundary of the Cape Colony and of British possessions in South Africa was the Orange River. Since then the gradual opening up of the trade route to the interior, culminating in the conquest of Matabeleland, has extended British territory in an unbroken line of 2000 miles, stretching from Table Bay to the shores of Lake Tanganyika, and the railway is steadily following the flag.

The Kimberley extension was opened to Vryburg, 774 miles from Cape Town, in December, 1890. This is the northern terminus of the Cape Government Railways, but that government has undertaken the working of the Bechuanaland Railway Company's line of 586 miles, which commences at Vryburg and was opened to Bulawayo in November, 1897. This line is said to have cost only £2,000,000, or under £3,500 per mile, and the British Government subsequently guaranteed a loan of a further £2,000,000 to carry the line on another 800 miles to Lake Tanganyika, probably following the route mapped out by the African Transcontinental Telegraph Company, whose wires have been opened to Blantyre, in Nyassaland, and are expected to reach Abercorn, at the foot of Lake Tanganyika, this year. The wire will then stretch 600 miles through the Congo Free State to Uganda, for which the necessary funds have been voted by the shareholders.

This great undertaking of connecting Cape Town with Cairo, which was looked on as the dream of a visionary a few years ago, is, therefore, in active course of fulfilment, and with our recent experience of both cables broken down at the same time, we cannot help wishing it every success. The Beira Railway has been opened to Umtali, and a service of traction engines is running from there to Salisbury. This line is 218 miles long, 2 feet 6 inch gauge, but the extension to Salisbury will be on the South African standard, 3 feet 6 inch gauge.

There are at present 4729 miles of railway open and working in South Africa, and at least a further 2700 miles are either actually under construction or shortly will be. This is a remarkable development when it is remembered that ten years ago there were barely 2000 miles completed, and twenty years ago not more than 500 miles, and that these first 500 miles had taken 20 years to get authorised and built. Of the total miles open 2264 are in the Cape Colony, 465 in Natal, 361 in the Free State, 777 in the Transvaal, 604 in Rhodesia, and 256 in the Portuguese territory. The Cape total includes six or seven private lines, several of which are of considerable importance.

The oldest is the Cape Copper Company's line of 100 miles, from Port Nolloth to O'okiep, which is interesting as containing the severest gradients probably anywhere worked on the ordinary traction system. The ascent of the Klipfontein mountain, with its rise of 1330 feet in 7½ miles, gives a mean gradient of 1 in 29.8, but includes several sections of 1 in 19. The gauge is 2 feet 6 inches, and the line, originally laid for animal traction with 18 and 28-pound rails on longitudinal sleepers, but since re-laid with 32-pound steel rails on cross-sleepers, was opened in January, 1876. The special engines constructed by Kitson & Co., of Leeds, for the steep gradients have been working very successfully since October, 1890. They have six coupled wheels, 3 feet diameter, wheel base 6 feet 3 inches, cylinders 14 × 21 inches, running weight of engine 27 tons, 4-wheeled tender, 11 tons. The total cost of the line, including the jetty at Port Nolloth, was £170,000, and in the year ending April 30, 1897, the railway made a profit of £9675.

This line was built to serve the Namaqualand Copper Mines, one of the most profitable industries in the colony. The Cape Colony Company owns most of the payable mines, from which about 30,000 tons of ore, averaging nearly 20

THE EAST LONDON BREAKWATER, SOUTH AFRICA

per cent., are extracted annually, some being smelted locally and the rest shipped to Wales. The total profit made last year was £215,238.

The other private lines are all on the 3′ feet 6 inch gauge, feeding the main lines of the colony, and have been mostly constructed under subsidy from the government of about £1500 per mile. The Kowie Railway Company's line, 43 miles from Grahamstown to Port Alfred, was opened in 1883, but owing to the decline of the Port, which has been deserted by the shipping trade after an expenditure of over half a million of money, the railway is now little used except by holiday-makers. The new Cape Central Railways, Limited, own the line from Worcester to Ashton, 42 miles, originally opened in 1889, and now being extended a further 40 miles to Swellendam. The Metropolitan and Suburban Railway of 3¾ miles from Capetown to Seapoint, opened in 1892, has suffered from the competition of the electric tram.

Much more important is the Indwe Railway Company's line of 66½ miles, which was opened in 1896, and is worked by the government as a branch of the Eastern system, which it joins at Sterkstroom. For many years the railways and the diamond fields were supplied with Welsh coal at a cost of £8 10s. per ton, delivered at Kimberley, of which £6 per ton was the charge for haulage from Port Elizabeth. Colonial coal from the Indwe and Stormberg Mines is now delivered in Kimberley at about £2 10s. per ton, and some idea may, therefore, be formed of the benefit which the coal mines have conferred on the diamond industry, and the extent to which that industry was taxed in former years to help to make a revenue for the railways. At a low estimate three or four millions sterling were wasted in Kimberley for the luxury of burning imported coal during the years prior to being connected with the coal fields of the colony, not to speak of the waste in the wholesale destruction of timber for fuel, which, unfortunately, is still going on.

The lines owned and worked by the Cape Government amount to about 1990 miles, and have cost, with rolling stock, about £20,000,000, or, say, £10,000 per mile. This does not include the lines through the Free State, which were handed over at the beginning of 1897 for £2,600,000, or £7200 per

mile. The capital invested in the Natal lines is about £6,750,000, or £15,000 per mile. The 717 miles of the Netherlands Company have cost nearly £9,000,000, or £12,500 per mile. This gives a total of over £38,000,000 for the cost of 3500 miles of railway owned by the above four administrations. If we add the probable cost of the extra 1200 miles owned by the various other administrations in the country, the total expenditure to date on railway construction in South Africa may safely be put down at not less than £42,000,000, or, say, at the rate of £56 per head of the white population of the country, which does not average more than 163 per mile open.

PHOTO BY BARNETT

THE RAILWAY STATION AT CAPE TOWN

Considerable as this expenditure is, it has been amply justified by the results, more especially since the through connections to Johannesburg have been completed. In 1896 the total earnings of the Cape Government Railways were over £4,000,000, of the Natal Railways over £1,000,000, and of the Netherlands Company nearly £3,000,000. The earnings per mile open were, in the Cape £1810, in Natal £2824, and in the Transvaal £4650, or per train mile run in the Cape 8s., 2.0d., in Natal 9s., 11.7d., and in the Transvaal 17s., 1d. The expenses per mile open were, in the Cape £853, in Natal £1049, and in the Transvaal £1620, or per train mile 3s., 10.2d. in the Cape, 3s., 8.47d. in Natal, and 7s., 0½d. in the Transvaal. The expenses per cent. of earnings were, in the Cape 47.1, in Natal 37.14, and in the Transvaal 41.25. The net receipts per cent. of the capital invested were, in the Cape £8, 19s., 7d., in Natal £11, 9s., 0½d., and in the Transvaal £20, 5s., and the net profit after paying interest on capital was, in the Cape £1,221,675, in Natal £464,762, and in the Transvaal £1,328,424, or a profit made by the three administrations in 1896, after paying interest, of over

A RAILWAY MAP OF SOUTH AFRICA

£3,000,000. This does not include the Free State share of profits, which for that year amounted to £289,553.

The results for 1897 are not so good, but still the Government Railways made a profit, after paying interest, in the Cape of £463,387, in Natal of £204,731, and in the Free State of £444,872. The Netherlands Company's returns are not yet available, but the total surplus profit for 1897 of the four administrations, after paying interest, was probably not less than £2,000,000.

The position of the Free State railways is a peculiarly favourable one. The amount agreed to be paid to the Cape for the handing over of the railways was a little over 2½ millions, but of this sum £800,000 was already in the hands of the Cape Government, being accumulated share of profits due to the Free State, leaving a balance of about £1,700,000, for which the Cape ac-

cepted debentures bearing interest at 3½ per cent. per annum. The Free State is thus in the pleasant position of having acquired, at the expense of a debt of under two millions, railways bringing in a yearly profit of half a million sterling, on which only £60,000 per annum has to be paid for interest, and can, therefore, every year set aside a handsome surplus, either towards the extinction of its debt to the Cape, or for the construction of new lines. For the present the latter course has been adopted, and by a Volksraad resolution of October, 1896, the following new lines were authorised, and are now under construction:—(1) from Springfontein to Fauresmith; (2) from Bloemfontein to Wepener; (3) from Wynberg Road to Clocolan, with branches to Ficksburg and Ladybrand; (4) from Wolvehoek to Bethlehem; and (5) from Bethlehem to Harrismith. An offer has been made to complete these five lines at a cost of not more than £6850 per mile, bearing interest at 3½ per cent. Last year the Free State Raad decided to build a railway by concession from Bloemfontein to Kimberley and to extend the Springfontein-Fauresmith line so as to join the Bloemfontein-Kimberley line at a point at or near Petrusburg. The Fauresmith line will serve the diamond mines of Jagersfontien and Koffyfontein, greatly reducing the cost of coal and other working expenses, and will place them in rail communication with Kimberley, where the headquarters of the mining companies are situated. But these new lines will have much more far-reaching effects than this.

The Springfontein-Fauresmith extension will form a direct route between East London and Kimberly, shortening the present route by about a hundred miles, so that instead of Port Elizabeth being 60 miles nearer to Kimberley than East London, as at present, the latter port will be 40 miles nearer than Port Elizabeth, and should get back a large part of the diamond fields trade which it lost 15 years ago, together with a good share of the Rhodes-

PHOTO BY BARNETT

AT PORT ELIZABETH

PHOTO BY BARNETT

THE BREAKWATER AT DURBAN

ian trade. The Bloemfontein-Kimberley line will reduce the present rail distance between Kimberley and Johannesburg by nearly 300 miles, and may possibly become the mail route between Johannesburg and Cape Town, for, though it will not appreciably reduce the distance, it will avoid the junctions of Springfontein and Naauwpoort and the intervening section over which a congested goods traffic passes. It will, of course, also reduce the present distance between Kimberley and Durban by 300 miles, and when the Harrismith-Bethlehem-Wolvehoek lines are finished, this distance will be reduced by a further 100 miles.

In the Cape Colony powers have been granted to the Grand Junction Railways, Limited, to construct several lines under a subsidy voted in 1895, to form a direct route parallel with the south coast from Cape Town to Kingwilliamstown, via Caledon, Oudtshoorn, Klipplaat (on the Graaff-Reinet line), Somerset, Bedford, and Fort Beaufort. Work on these lines, in all about 460 miles, was commenced in 1896, but some delay has taken place. One of the lines will connect Oudtshoorn with the coast at Mossel Bay, a distance of 70 miles.

Surveys have been made of many other new lines proposed to be constructed, the most important of which is a line through Kaffraria to the Natal border, with a probable branch to Port St. Johns. Surveys have also been made of a proposed bridge over the Buffalo River at East London. How necessary these coast lines are to shorten the land journey between the ports is very clearly seen by a comparison of the distances by sea. From Cape Town to Durban is 930 miles by sea and at present 1494 miles by rail; from Cape Town to Port Elizabeth is 490 miles by sea and 839 miles by rail, and to East London 640 by sea and 901 by rail. From Port Elizabeth to East London is 150 miles by sea and 548 by rail; from East London to Durban 290 miles by sea and 1145 miles by rail.

Meanwhile, the Natal Government is proceeding with the construction of the North and South Coast lines, the former through Verulam towards Zululand, and the latter towards the Cape border. Another south branch was opened to Richmond in December, 1897, and may

possibly be subsequently extended to form a junction with the cape line through Kaffraria. These three lines are being laid with 45-pound rails released from the main line, which is being re-laid with 80-pound steel rails on karri and jarrah wood sleepers, 7 ft. 3 in. × 9 in. × 4½ in.

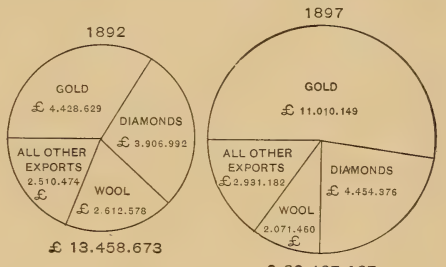
In the Transvaal no extensions are being made to the Netherlands Company's lines, but powers have been granted to build five or six other lines, (1) from Pretoria, via Nylstroom, to Pietersburg, now open to the Warm Baths (60 miles from Pretoria); (2) from Komati Poort to Leydsdorp; (3 and 4) from a point on the Delagoa Bay line at or near Machadodorp to Lydenburg in the north and to Ermelo in the south; and (5) from Vryheid to Dundee, in Natal. It is also proposed to build a second line of railway south of Johannesburg from Boksburg to Krugersdorp, for the conveyance of coal and explosives, etc., to the mines. This line will be built by the Netherlands Company.

There is at present apparently no intention to extend the south-western line beyond Klerksdorp, though the extension of this line to the border at or near Fourteen Streams would be a great boon to the travelling public, as it would shorten the distance between Johannesburg and Cape Town by fully 50 miles. In this connection, it is important to mention that the advisability of laying down a third rail, 4 feet 8½ inch gauge, between Cape Town and De Aar, is engaging the attention of the Cape authorities, as it is estimated that this would save at least six hours, and enable passenger trains to be put on equal to the best to be found in other countries.

The question of doubling considerable sections of the main line and flattening the gradients is also under consideration. With the exception of the Hex River Pass, where for over 20 miles the gradients are 1 in 40 and 1 in 45, there is nothing in the Western system to prevent a high rate of speed being obtained were the wider gauge adopted, and if this were done, and the Klerksdorp extension sanctioned,—which it is hoped would also be on the 4-foot 8½-inch gauge,—there is no reason why the journey from Johannesburg to Cape Town, instead of taking 48 hours, as at present, should not be accomplished in about half the time.

The railways are the most conspicuous evidence of engineering progress in South Africa, but great advances have been made with other works of public utility. Twenty-five years ago there were only 781 miles of telegraph open, and a message of twenty words from Cape Town to East London cost 17s., 6d. To-day there are 19,000 miles of wire working in the Cape Colony, and probably a further 10,000 miles in the other States and colonies.

Within the same period several thousands of miles of excellent roads have been made, including many grand mountain passes, and nearly every river of any magnitude has been spanned by substantial bridges. The great Zwartberg Pass, which rises 3400 feet in the



SOUTH AFRICAN EXPORTS

11 miles from base to summit, is one of the finest works of its kind to be seen anywhere. Shipping accommodation at the ports has been much improved and extended, and a dangerous coast rendered safe by the construction of numerous lighthouses.

The rapid increase in population, which has more than doubled within a generation, has necessitated municipal works being undertaken, and for many years to come the improved paving, draining, lighting, and water supply of towns will offer employment to a large number of engineers. At last the country is waking up to the need of irriga-

tion, and the success in boring operations in different parts of the Cape Colony makes it probable that not only will the storm waters of the rivers be prevented from running to waste, but underground water supplies will be tapped, and vast tracts of land brought under cultivation, or rendered valuable for pastoral purposes. Meanwhile, private enterprise in the Transvaal has introduced steam ploughing, and many other industries have arisen, more or less allied to engineering, such as brewing, milling, and the manufacture of bricks, cement, and glass, not to mention dynamite.

The last-named industry at once suggests the larger industries to which the whole country owes whatever prosperity it can boast, and its present position of importance in the world. The writer cannot do more here than mention the broad facts of the case. The Griqualand West Mines have produced to date £80,000,000 worth of diamonds, and are still steadily producing at the rate of £4,000,000 per annum. The Witwatersrand Mines have produced in the last ten years £55,000,000 worth of gold, and one recent month's output was at the rate of £14,500,000 per annum. Prior to the discovery of the mines, thirty years ago, the total trade of South Africa, —that is, exports and imports combined,—was not £5,000,000 per annum. To-day it is nearly £50,000,000, and of the total export 80 per cent. consists of minerals. This is the main outstanding fact in the present economic conditions of the country.

In conclusion, mention should be made of the wise provision of the Cape University to establish a School of Mines in connection with the South African College in Cape Town. The first batch of students came up for their final examination in Johannesburg last June, after spending a year in the mines there, and a year in Kimberley, and afforded every evidence of excellent training and of downright earnest study and hard work.

ENGINEERING FALLACIES

LIQUID AIR AS A MOTIVE POWER

By Dr. Henry Morton, Prest. Stevens Institute of Technology

IN January number of 1895 of this magazine, there was published an article by the present writer under the title *Engineering Fallacies*, in which the position was taken that whenever any machine or process was brought to the attention of an engineer, which appeared to violate the general doctrine of the "conservation of energy," it might properly be condemned on that ground alone, without further investigation, or if any investigation was made, it should be directed to the discovery of some mistake or fraud and not carried out as though some new law of nature or new property of matter was to be studied.

Greatly to the surprise of the author, it transpired, from comments in engineering journals of high standing, that the true character and universal application of the doctrine of conservation of energy were not adequately appreciated in all cases, even among such guides of the public, and that some of these were quite ready to contemplate such a violation of the conservation of energy as would constitute what is known as perpetual motion as something attained or attainable, and a worthy subject of study and experiment by inventors. The discovery of this state of affairs led to the preparation of two other articles under the same title which were published, respectively, in the issues of this magazine for April and August, 1895.

In these articles it is believed that the subject of energy conservation and the reasons for our unqualified acceptance of the doctrine were fully treated, and it is, of course, not proposed to go over the same ground again; but a recently published article on *Liquid Air* by Charles E. Tripler, of New York, makes it obvious that some further explanations as to the relation of the conservation of energy to other subjects might be profitably entered upon at the present time.

It is quite usual to say that as a result of the law of conservation of energy we cannot have "power for nothing," meaning thereby that we cannot use energy in the doing of work (which always involves the transformation of one form of energy into another) without supplying, from some source, an amount of one kind of energy fully equivalent to the amount of the other kind developed.

Thus, if we use the heat energy derived from burning coal to operate a locomotive and draw a train of cars, we must expend as much heat energy and burn as much coal as will be the full equivalent of the motion-energy given to the train, not to mention other concomitant transformations of energy which we often refer to as "losses." And so on with all other transformations such as those involving the work of producing electric currents, light or heat.

There is, however, another sense in which we may say that we can get power for nothing, meaning that we may obtain power for doing work by using energy freely supplied by nature

without cost to ourselves. This, for example, would be true of a wind-mill or a water-wheel, or the gas from a gas well, disregarding any outlay needed to make the wind, or water, or gas available.

Any of these sources of energy might cost the man using them nothing, and yet this would in no sense violate the law of conservation, because the energy in the wind, or the water, or the gas would disappear just in proportion to the work done, or the development of the kind of energy directly concerned in doing it. What would violate the law of conservation would be the statement that, by a certain machine or method, more energy or work was secured than was taken out of the wind, water or gas used. In this sense, then, we may say that we can get power for nothing, if nature gives it to us, or it is donated by a friend, as if some one presented us with a thousand tons of coal.

A less simple and obvious case of such a gift from nature would be the power directly developed in a "solar engine" heated by the rays of the sun. The late Captain Erricson spent many of the last years of his life in developing such a solar-engine, and at the Paris Exposition in 1880 a small newspaper was printed on a press operated by a solar-engine designed by M. Mouchot.

Going a step further, there would be nothing contrary to the theory of conservation in proposing to use the ordinary heat of the atmosphere as a source of energy and work, provided we had also a free supply of cold water or a means of obtaining a lower temperature without expending work to secure it.

In other words, suppose we had in some locality a steady breeze of warm air and a good stream of cold water, so that we could use the warm breeze to expand a volatile vapour and the cold water to condense or contract it again! We might then obviously operate some sort of engine, like a steam engine, with the energy thus given us by nature, and the power so obtained would, in the sense we have been considering, cost us nothing. It would be to us a free gift.

Let us, however, disregarding the proverb, "look this gift-horse in the mouth" by making some calculations as to its actual value. Leaving out of consideration all matters of detail in machinery and method, let us assume that we have some apparatus which will allow us to take 20° F. of temperature out of the warm air with which nature is supplying us, reducing such air, say, from 70° F. to 50° F. as it passes through, or in contact with, the machine.

Now, approximately, 8 pounds of air, changed in temperature 20° F., will represent the number of heat units equivalent to the work of one horse-power for one minute. For each horse-power, then, we should have to pass 8 pounds of air each minute through, or over, our machine, so as to make it part with 20° F. of its temperature.

Eight pounds of air, however, at ordinary atmospheric conditions occupy the space of about 100 cubic feet. For a 1 horse-power engine, therefore, we should be obliged to pass 100 cubic feet a minute through, or over, the apparatus used to abstract its heat, and for a 10 horse-power engine, 1000 cubic feet. Even before we begin to consider ways and means, this appears a very serious undertaking; but when the actual conditions of the problem are realised, the solution in any practical way is seen to be impossible, in view of the power needed to keep this air in motion, the great extent of surfaces required to enable it to communicate its heat rapidly, the eddy currents which would be set up and the losses due to friction. In fact, it is doubtful whether any apparatus could be devised in which the losses of useful effect, involved as above, would not absorb nearly all the power derivable from the air acted upon.

It would thus appear that the free gift of "power costing nothing," involved in a plan for using the atmospheric temperature, is, like some other donations, not as valuable as that which is earned at the cost of some work expended.

But it may perhaps be said,—suppose we do not rest satisfied with the moderately low temperature which nature

gives us in cold water, but use some very low temperature, such as that furnished by liquid air. May we not, then, take a vastly greater amount of energy out of the air at atmospheric temperatures by cooling it down to, say, —350° F.? Yes! that is true enough; but how are we to get this very low temperature?

Obviously the only practical way is by some mechanical process like that of Mr. Tripler, described in the magazine article previously referred to. Here, however, a difficulty at once confronts us. It requires the expenditure of work to make the liquid air, or anything else intensely cold. Will not the work so expended be much more than we can gain by using this low temperature?

To this question we can on general principles answer yes, without the need of any calculations which, in view of our ignorance as to the latent and specific heat of air, are troublesome to express in any concise shape because we must make so many assumptions. No matter what assumptions we make within the limits of rationality, however, we always get results which show a large excess of the power expended in securing the low temperature over the power gained by its employment. There is, therefore, nothing to be gained, but much to be lost, by an attempt to use low temperatures such as those artificially produced by Mr. Tripler's apparatus and method.

To avoid any misunderstanding, let me say that in the above I have no intention of suggesting that the method of using liquid air as a cooling agent is entertained or expressed by Mr. Tripler. I have referred to it solely because it seemed to me probable that it would suggest itself to some of my readers in connection with my argument as to the impracticability of using atmospheric heat to drive an engine or furnish power. Mr. Tripler's liquid air engine I will take up presently.

From all I have said above, I think it will be obvious, that while there is no conflict with the doctrine of the conservation of energy in the idea of getting some power for nothing from atmospheric temperature, aided by a supply of cold water, such a method is entirely impracticable on account of the smallness of the power so attainable and the bulk of the machine required, and that this difficulty would be in no way relieved by combining such a method with one for obtaining a very low temperature. This last proceeding would, in fact, be like attempting to increase the efficiency of a small fall of water by running the water into a pit, out of which it would have to be pumped up again.

Turning now to Mr. Tripler's method of getting "power for nothing" from the atmospheric temperature by the use of liquid air, we find it very simple, indeed. He has an iron tube into which he pours about a quart of liquid air. This tube serves him as a boiler, being heated, not by a fire, but by the warm air in his laboratory, whose heat vapourises the liquid air. This boiler is then connected with a small steam-engine cylinder which is operated by the air from this boiler charged with liquid air, just as it would be by steam from a boiler charged with water and heated by a fire. So far, so good; but let us now use a few figures and find out the amount of power attainable in this way, assuming, for Mr. Tripler's benefit, that his boiler could be operated on a large scale in the manner indicated.

Mr. Tripler tells us, and, indeed, we know from other sources, that liquid air, if expanded to gas and heated to a temperature of 70° F., will increase in volume about 800 times. Starting with this, we can determine by a familiar and much-used formula* just how many

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* NOTE.—This formula is as follows:—

$W = p_2 v_2$ hyperbolic logarithm $\frac{v_2}{v_1}$ in which

W = work done in foot-pounds pr. pound of air.

p_2 = final pressure of air in pounds pr. square foot = 2117.

v_2 = final volume of one pound of air in cubic feet at the temperature which we assume as kept at 70° F. during the expansion = 13 34 cubic feet.

$\frac{v_2}{v_1}$ = ratio of expansion, from state of liquid to that of gas at 70° F. We know this ratio to be a little less than 800, but will take it as 800, for the sake of round numbers, and to agree with Mr. Tripler's figures.

v_1 would represent the initial volume of one pound of the air. This we do not know accurately; but

foot-pounds of work a gallon of liquid air could do if thus heated and expanded in a perfect engine; that is, one having no friction or other cause of loss.

This would be about 1,900,000 foot-pounds, and if this were done during an hour, it would be almost exactly one horse-power-hour, as one horse-power-hour is equivalent to 1,980,000 foot-pounds. If, therefore, Mr. Tripler's engine was ideally perfect, and lost nothing by friction or otherwise, it might give him one horse-power-hour for every gallon of liquid air used in it.

But we have seen already, from the statements in the article by Mr. Tripler, that he requires 10 horse-power-hours to make a gallon of liquid air. Getting, then, as an ideal maximum but one horse-power-hour in his engine from a gallon of liquid air which cost him 10 horse-power-hours for its production, it is obvious that Mr. Tripler is very far from getting "power for nothing" by this means.

In the face of these facts, derived from, or confirmed by, the article here considered, it is manifest that the statement, more than once repeated in the same article, that Mr. Tripler has made 10 gallons of liquid air by the use of only three, must be the result of some prodigious mistake.

If that statement were true, it would, indeed, be a violation of the law of energy conservation; but as I have shown, Mr. Tripler's article itself furnishes us with data adequate to the disproving of this impossible statement.

In conclusion, then, I am constrained to say that while Mr. Tripler has done excellent work in improving the methods of liquefying air, so as to produce this remarkable product with relative ease and economy, he has been led very far astray by enthusiasm and inexact observation in so far as he claims for liquid air any value as "a new substance that promises to do the work of coal and ice and gunpowder, at next to no cost," or makes statements about it which conflict with the thoroughly established doctrine of the conservation of energy.

All that can be truly said in favour of Mr. Tripler's idea of obtaining power from the heat of the atmosphere could be said with much more force by a manufacturer of wind-mills, for it is demonstrable that "power costing nothing" can be more easily and efficiently obtained from wind-mills than from any apparatus deriving its power from "atmospheric temperatures," meaning thereby the heat found in the atmosphere.

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as we do know, or may safely assume the value of $\frac{v_2}{v_1}$, this is of no consequence.

Substituting these values in the above equation, we have $W = 2117 \times 13.34 \times 6.685 = 188,800$ foot-pounds, or, to be liberal to Mr. Tripler, say, 190,000 foot-pounds. It is, perhaps, unnecessary to say that 6.685 is the hyperbolic logarithm of 800.

DREDGING FOR GOLD

By A. W. Robinson, M. Am. Soc. C. E. and M. E.

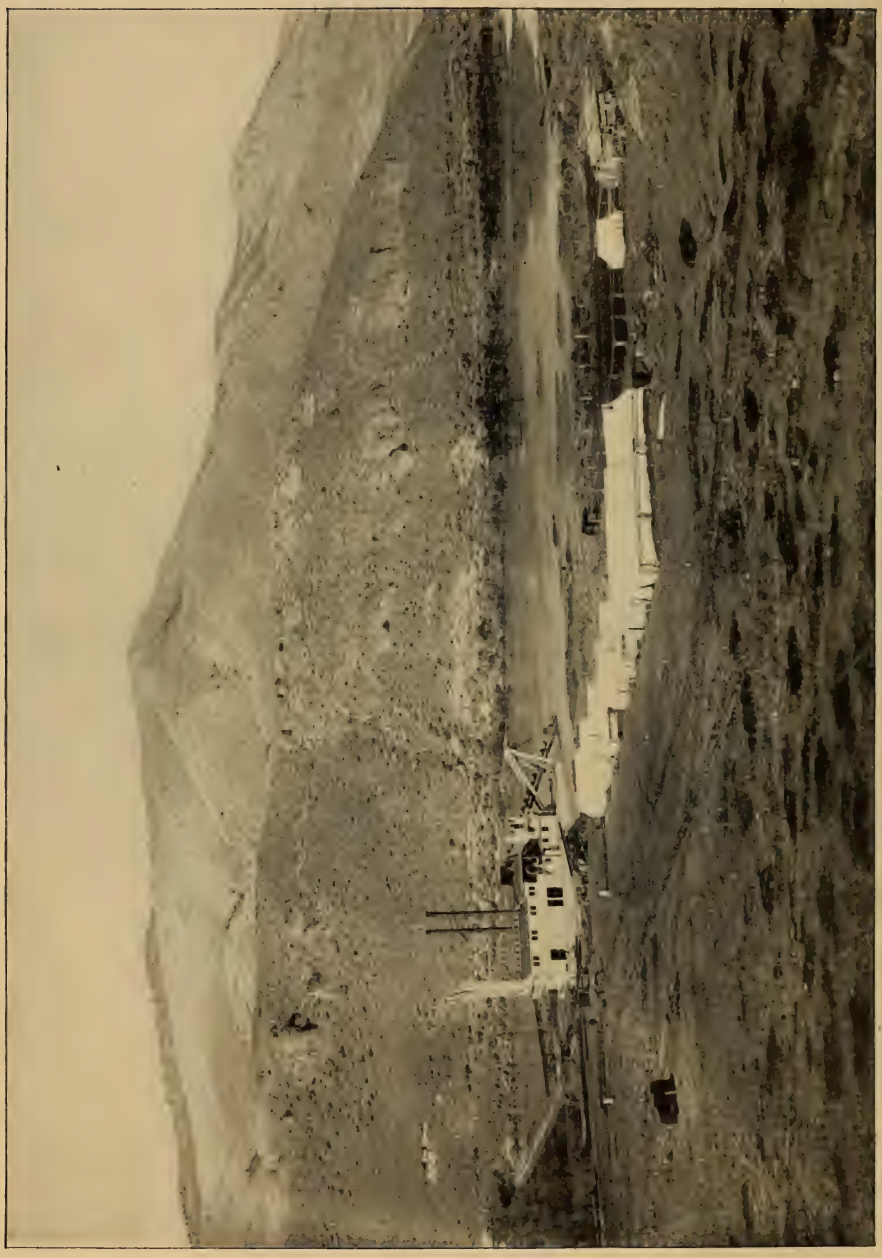
"PANNING OUT"

COINCIDENT with the decline of hydraulic mining for gold in the Great West of the United States, is the rise and development of a new process for recovering the precious metal from the alluvial bottoms and river beds which have heretofore been deemed inaccessible. It is the later and more perfect process succeeding the earlier and cruder one, and it makes available vast deposits of gold-bearing gravel which is beyond the reach of hydraulic mining.

Hydraulic mining is at once the simplest and most effective method of saving the bulk of the gold where the conditions exist for its use; but more or less loss occurs in the tailings. Hydraulic mining is the disintegration and washing down of a bank of auriferous gravel by means of a powerful jet of water, and the passing of the resultant water and *débris* off through a sluice-box containing riffles in which the gold is caught. Two essential conditions are necessary to successfully operate this system:—First, the water must be available in large quantity and under heavy pressure; and secondly, there must be a "dump," or natural grade, for the water to run off and deposit the tailings without interruption.

These conditions are found in many places along the banks of rivers and creeks and in the valley sides, situated so that the water can be laid on by a ditch or flume, which taps the stream near its head waters, and, following down the contour of the valley at a gentle grade, is soon far above the river bottom, which has descended more rapidly. A pipe line carries the water down to a "giant" nozzle, which, by the force of a stream, sometimes as much as 6 inches in diameter, from a pipe-line 18 inches in diameter, and with a pressure of several hundred pounds per square inch, does tremendous execution in washing down whole hillsides and spreading them out in the valley below. This harnessing of the forces of nature is so simple and efficacious, so free from complication, and so cheap as to operating expenses, that handsome returns are obtained, notwithstanding its wastefulness.

This simple and attractive system soon began to decline for the reason that the localities favoured by nature became gradually exhausted and worked out. Furthermore, the vast volumes of *débris*, washed down into the rivers and fruitful valleys below, became a menace to agriculture and other occupations, so much so that the United States Government appointed the "California Débris Commission" to investigate and regulate the conflicting interests. The proceedings of this commission, and the record of the strife between the gold miners and the land



A BIRD'S EYE VIEW OF THE VALLEY OF THE GRASSHOPPER AT BANNOCK, MONTANA, U. S. A.

and navigation interests, furnish an interesting chapter in the history of American gold mining, particularly in California.

The gold in these placer deposits is in the form of finely divided particles, scattered through the gravel. The value is very variable, 10 to 15 cents per cubic yard being accounted poor ground, while 50 cents to $1 would be rich pay. Occasionally pay streaks are found which will run $5 and even $20, or more, per cubic yard, but such streaks do not represent the general average of a deposit.

A cubic yard of gravel and sand will weigh about 2800 pounds, or nearly a ton and a half. Fifty cents' worth of gold scattered through this quantity, at $20 an ounce, will weigh only 12 grains. The proportion of gold to gravel by weight is, therefore, 1 to 1,630,000. Inasmuch as gold is eleven times as heavy as gravel, the proportion by volume would be 1 to 17,000,000.

This 50 cents' worth of gold is found usually in finely divided particles. If the particles weigh only a grain apiece, it is called " coarse " gold and can be readily saved in a sluice-box, although the particles are not larger than ordinary sand. Fine gold is of various degrees of fineness down to minute floating particles, scarcely visible to the naked eye, and of which it requires several hundred to make a cent's value.

The marvelous ease with which the apparently infinitesimal and elusive yellow grains, lost amid millions of tons of earth and stones, can be recovered is due to the great specific gravity of gold. Being eleven times heavier than sand and nineteen times heavier than water, it is only necessary to wash the two together, when the gold sinks to the bottom and the lighter sand and gravel are carried off by the rushing water.

The beautiful simplicity of the hydraulic sluicing process in all its forms causes it to be the most widely adopted of any method of gold saving. Its efficiency in fine gold is from 40 to 60 per cent., and in coarse gold, from 70 to 100 per cent. If the gold is wholly coarse, it will save it all.

This lack of efficiency has led many inventors to devise means to save that fraction of the fine gold that is lost in sluicing, but thus far with indifferent success. Several methods of amalgamation have been successfully used, but for thorough work their capacity is so limited that they do not pay.

The gradual erosion of the gold-bearing banks by the streams and rivers naturally causes a deposition of strata lower down, containing more or less gold. These alluvial bottoms, sedimentary bars and beds of streams have, until recently, been considered as beyond the reach of any ordinary method of working.

They were not capable of being washed or sluiced, because they were

THE ROCKER

already at the lowest level. Various attempts to dig the material up and elevate it into sluices, from which it could be worked, were made; but the constant presence of water in such workings and the great cost, or impossibility of drainage, rendered such efforts abortive. Miners were compelled to be content with scratching the surface or sinking shallow pits until overcome by the water, and speculating upon the unknown and untold riches that lay just beneath their feet.

The bottom of the alluvial deposit, or " bed rock," as it is termed, is generally where the richest pay is found,

due to the natural gravitation of the gold. Thus it comes about that attention has been turned to dredging as a method of reaching these deep and submerged deposits effectively. On the face of it a simple enough problem, yet

CLEANING UP A SLUICE BOX

what vast sums have been spent in the mistaken efforts of those who did not fully appreciate all the conditions involved, and how elusive the little yellow grains are when attacked under water! The seductiveness of the gold attracts many to engage in a mad and determined search for it, and it is not strange that, like moths around a candle, some should come to grief.

The truth is that gold mining is a business which must be learned, like any other business, and it is just as amenable to the natural laws which govern it as any other of the practical sciences. What would be said of a tailor who engages in watch making, or of a merchant who endeavours to design a bridge or a locomotive? Yet we see the merchant, the manufacturer, and the business man launch out into gold mining and make simple calculations of the enormous wealth that can be taken out of their claims at so much per cubic yard, and assume all the responsibility of the practical and technical work. The primitive mode of hand washing is by the "pan,"—a shallow dish of sheet steel about 18 inches across and 3 inches deep, with a flat bottom and flaring sides. The little cut at the head of this article shows a miner panning out some samples with which he seems well satisfied. The much-used expression "pan out" has its origin in the early gold-mining days when, after careful washing down to the last fine particles, the results in the pan were eagerly looked for. Inasmuch as there are about a hundred pans to the cubic yard, it will be seen that a cent's worth of gold to the pan would be valuable ground when worked by modern wholesale methods

"Panning" gold is a simple and rapid operation to an experienced miner, but to the novice it is slow and laborious. By a few gyratory movements with the lip of the pan under water the bulk of the gravel is quickly washed over the edge of the pan, while the gold settles to the bottom. The process is then continued, with repeated lappings of the water carrying off a little sand and gravel each time, until there remains only a small quantity of the heavy magnetic "black sand" always found in gold-bearing gravel. In this sand the occasional gleam of a golden "colour" is seen, and then comes the interesting and delicate part of the operation. Every grain of black sand must be carefully washed away, leaving the grains of gold perfectly clean.

The determination of values can be made only by weighing the results of a large number of pans, or from a definite volume of material, but the number of "colours" to a pan is often used to

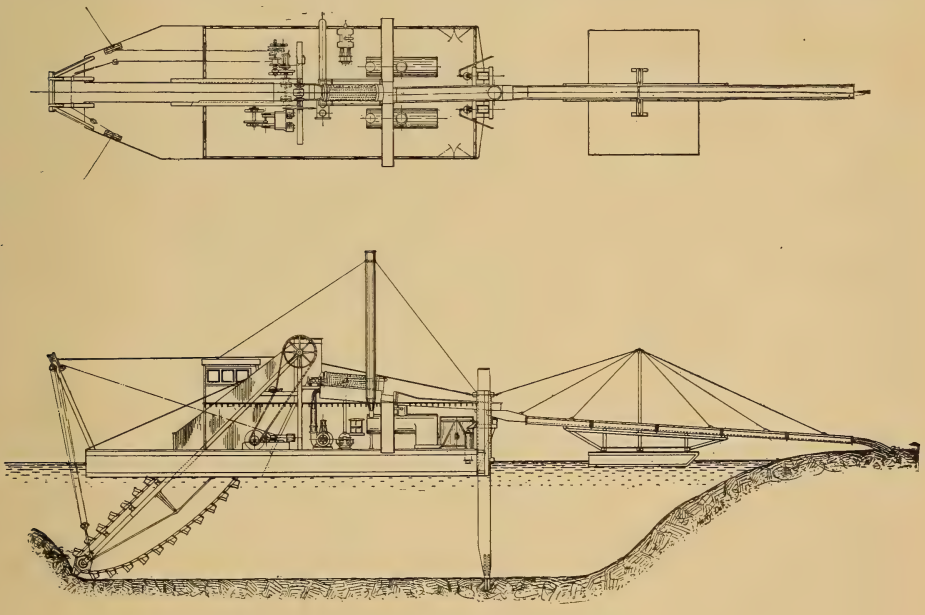
indicate values. A "colour" is a particle of gold apparent to the eye, and as the visible particles vary in size from a pin's point upward, they can have no definite value.

Next following the "pan" is the "rocker." This is the panning operation performed continuously in a wooden box mounted on rockers, and fitted with a sieve and shelves below which serve as sluice-boxes for catching the gold. The miner, as shown on page 35, shovels the gravel into the rocker, then rocks it with one hand, and dips water into it with the other. Many wandering miners make a living by "rocking" out the surface gravel in selected spots along river bars and in favourite points in valley-bottoms.

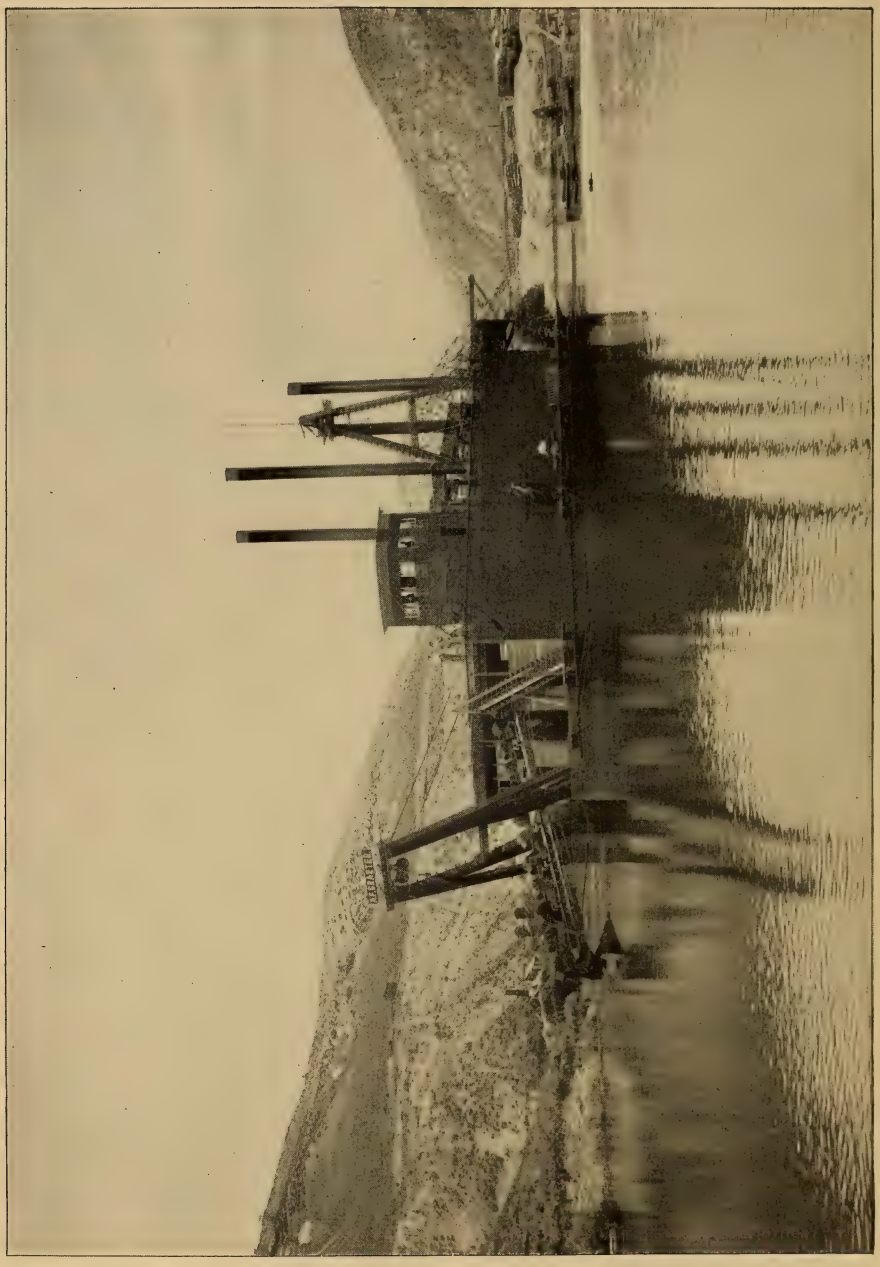
From these primitive methods came the suggestion of the larger and more wholesale methods of dredging. It was only necessary to combine a dredging machine and a sluicing and washing apparatus in order to reach at once these precious deposits. The problem proved, however, much eless simple than it seemed, and many experiments were tried before the final type of dredge was evolved and perfected.

Almost every known type of dredge has been tried for gold dredging. One of the most attractive types is the suction, or hydraulic dredge, which sucks up the sand and gravel with a large quantity of water. The water, thus pumped up, thereafter serves the purpose of sluicing, being practically one operation. There is a difference of opinion concerning the utility of using a centrifugal pump, or suction dredge, for handling gold-bearing gravel. It is claimed by some that grains of gold can be elevated and carried through the discharge pipe of the pump, because the velocity of flow is so much greater than the velocity at which grains of gold will fall through the water. This is true, and if the grains of gold could be introduced into the mouth of the suction pipe they would assuredly be elevated and passed through the pump into the riffles, and would there be caught.

But this is not the difficulty with this form of dredge. The difficulty is that the force of the suction, being intense close to the suction pipe and rapidly decreasing in intensity a short distance from the suction, causes all the sand and gravel to be picked up and leaves



PLAN AND SECTION OF A GOLD DREDGER



A REPRESENTATIVE TYPE OF GOLD DREDGE

the gold behind, due to its greater specific gravity. Furthermore, the suction dredge cannot work in stones or bowlders. The use of a centrifugal pump, therefore, for cleaning up the bottom and picking up the gold is impracticable, especially if the gold be coarse and the bedrock uneven. A rotary cutter on the suction pipe does not remedy the difficulty, because it only agitates the gravel and further precipitates the gold.

The dipper dredge has also been used, but in most cases has been abandoned, although it is an admirable machine as a dredge and will handle any ordinary material. It is not adapted for placer-mining, because it disturbs the gravel in the act of digging, so that a considerable portion of the gold is lost. It is well known that agitation of gold-bearing gravel under water induces the precipitation of the gold; in fact, it is precisely this quality on which the whole operation of sluicing and gold washing depends.

It is, moreover, mechanically impossible to construct a dipper door which will be absolutely water-tight. Naturally, therefore, much of the fine gravel in the bottom of the dipper leaks out and carries gold with it. Various packings and devices for making the dipper door water-tight have been tried, but none are successful. A certain amount of looseness is necessary to its proper working. A bit of gravel would prevent a tightly fitted door from closing, and it would inevitably become loose by wear in any case.

Another objection to the dipper dredge is that it deposits the material intermittently, several tons at a time, and at a long distance from the centre of the dredge, so that it is difficult to take care of the material delivered in this way. It is necessary to have a large hopper either on the bank or on an auxiliary scow, and to feed the gravel out of this hopper into sluice-boxes or other appliances.

The same objections apply to the clamshell form of dredge to an even greater degree, as it is by no means water-tight, and loses most of the gold in the act of bringing up the gravel.

In the elevator dredge none of the foregoing objections are found. The action of the endless chain of buckets is slow and quiet, and the material is picked up clean from the bottom with the smallest amount of agitation, and in a manner best calculated to retain the gold. The buckets are water-tight, and retain their entire contents until emptied by inversion at the top. The delivery of material is continuous and at the centre at the boat, instead of being intermittent and at a distance over the side of the boat, as in the dipper dredge. The elevator buckets also bring up a considerable proportion of water, which facilitates the washing operation, and the material is brought up in smaller masses than in the case of the dipper dredge, and, hence, is more easily broken and disintegrated in the screen. For all of these reasons it is the ideal type of dredge for river mining. This conclusion is confirmed by the fact that all the dredges in the Australian and New Zealand gold fields are of this type, and a large number of them are successfully in use there.

The elevator, or chain-bucket dredge, is not new; in fact, it is one of the earliest known types. Some very good dredges of this type were brought to America from the Clyde in 1832 for use on the river St. Lawrence. They had engines of the side-lever type, and did very effective work with 6 pounds of steam.

On the opposite page is shown a typical gold dredge. This machine consists of the following elements:—1st, the dredging apparatus proper, comprising the chain of buckets and means for driving them; 2d, a steel hopper into which the material is discharged; 3d, a revolving screen in which it is washed and by means of which the coarse stones are rejected; 4th, a sluice-box for carrying off the fine tailings and discharging them astern; and 5th, a centrifugal pump for furnishing the necessary water for sluicing and washing purposes. All these details have been successfully combined so as to make a complete machine, capable of dredging and treat-

AN ELECTRICALLY OPERATED DREDGE

ing 3000 cubic yards of material per day. The operations are simple and continuous, and under perfect control.

The vastness of the field thus opened up is incalculable. Thousands of miles of good gravel deposits, beyond the reach of all other known methods, can now be made available at a low working cost. One of these dredges can do the work of a thousand men working in the old way; and not only that, it can reach depths and clean up bedrock that would be totally inaccessible by the combined labour of any number of men. The work of gold dredges has already become a perceptible factor in the world's production of gold, and it is yet in its infancy and is bound to increase.

Among the earliest successful dredges are those at Bannock, Montana, on Grasshopper Creek, in the United States, where three dredges are at work. The ground is not phenomenally rich, varying from 10 cents to 40 cents per cubic yard; but the dredges have maintained a steady average of work which has yielded "clean-ups" varying from $500 to $3000 per day.

On page 34 is shown a bird's-eye view of the valley of the Grasshopper with one of the dredges in the distance. The creek is quite small, averaging 20 feet wide by a foot deep; but the dredges work out the whole area of the valley bottom and work at different levels controlled by dams.

The whole field of dredging for gold is yet in its infancy, and it offers a promising field for investment under proper conditions. A large amount of placer-mining property yet remains to be opened up that can be worked only by dredging. The improvement of modern methods, by which large capacity can be maintained at low operating cost, renders the working of low-grade ground possible at a good profit. The proverbial uncertainty of mining is largely eliminated, and by taking proper precaution and proceeding on business principles, dredging for gold becomes simply a manufacturing proposition.

There are many good claims and river leases lying undeveloped for want of capital and for want of knowledge of

how to produce certainty of results. If the results can be assured with reasonable certainty, capital will not be slow to embrace the opportunity. Many costly experiments have been made, some of which have been total failures, some partial failures and some successes. Capitalists, naturally and wisely, are reluctant to put money into schemes that may result in similar failure. An intelligent examination of these cases shows that in every instance failure has been due to some evident cause.

Some of these causes are the following:—

1st, the adoption of the wrong type of dredge, such as suction, clamshell, and other unsuitable types, which, for point of insufficient capacity, frequent breakdowns, inability to dispose of tailings, inability to clean "bed rock," inability to save the gold, and excessive cost of operation in proportion to work done; 4th, poor management; 5th, not enough gold in ground to pay; 6th, organisation by a "promoter" for stock jobbing purposes; 7th, operation by an "inventor" who has a new machine, and can do what no one else has ever done; 8th, lack of capital to efficiently carry on the enterprise; 9th, ground not suitable for dredging; and, 10th, character of gold such that it cannot be commercially saved.

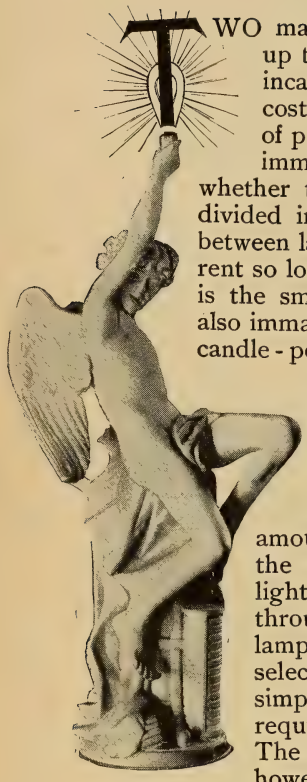
"Forewarned is forearmed," and to avoid these and other rocks and shoals

HYDRAULIC SLUICING

specific reasons, cannot be made a success for dredging gold; 2d, erroneous diagnosis of the conditions to be fulfilled as to the character of material and method of working, and the consequent lack of adaptability of the machine to those conditions; 3d, faulty design of the machinery, either in general arrangement or detail, so that it fails in it is necessary to have a knowledge of them. It is practically impossible for any one but an expert to determine all the points that must be covered from a mechanical, commercial and legal point of view; but enough has been said to indicate the general character of this new industry and the lines on which it can be successfully carried on.

SELECTION OF INCANDESCENT LAMPS

By Alton D. Adams



TWO main items go to make up the cost of light from incandescent lamps,—the cost of lamps and the cost of power. It is obviously immaterial to the user whether the charge to him is divided in any particular ratio between lamps and electric current so long as the total amount is the smallest possible. It is also immaterial at what nominal candle-power the lamps are rated so long as the desired amount of light is obtained at the smallest cost.

If all incandescent lamps took the same amount of power to give the same light, and this light remained constant throughout the life of the lamp, the problem of lamp selection would require simply a decision as to the required candle-power. The unfortunate facts are, however, that incandescent lamps of the same rated or initial candle-power require electric current, or watts, varying in amount by as much as 40 per cent., and that the candle-power of all these lamps drops rapidly and constantly from about the time they begin to burn.

The variation in watts required for lamps of the same nominal candle-power is not confined to any particular makes of lamps, but is common to all, and the purchaser, by specifying the candle-power and watts for his lamps, can get lamps of any wattage within the usual range of manufacture. In the matter of drop in candle-power after the lamps begin to burn, there is some difference between the various makes; but this difference is probably not so large as is sometimes represented, and it is not the intention to treat of it here, but simply to point out certain conclusions concerning the average lamp.

Prof. Benjamin F. Thomas, in the transactions of the American Institute of Electrical Engineers for 1892, reported tests made at the Ohio State University on a large number of incandescent lamps of the leading makes, giving a very complete record of watts and candle-power during the life of lamps. From the results of this test the diagram on the next page has been prepared to show at a glance the relation between candle-power, total watts consumed, and the watts per candle at various stages of lamp life.

The lower horizontal line is marked with the number of hours from the start during the life of the lamps, and the left-hand line with percentages of the initial candle-power, watts, and watts per candle corresponding to the three curves.

Curve *A* represents the drop in candle-power from the start during the twelve hundred hours of the test. At the start the light given by the lamp is taken as unity; at four hundred hours the light has dropped to about 78 per cent.; at eight hundred hours to about 62 per cent., and at twelve hundred hours to about 55 per cent. of the initial candle-power.

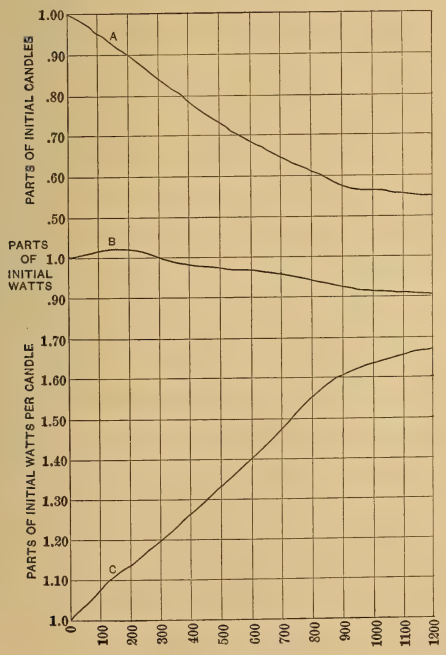
This curve makes it evident that, while the cost of new lamps may be saved by continuing old ones in use until they burn out, the light will be reduced to little more than half that at the start.

Curve *B* shows the variation between the power, or watts, taken by a lamp at the start and that required at each

period of its life. The watts at first consumed are taken as unity, and the power at other periods is based on it. From the first hour up to three hundred hours the required watts are greater than the unit, and then they gradually fall to about 91 per cent. of the amount at the start. Thus, while the light from a lamp has fallen 45 per cent. the watts it consumes have decreased only 9 per cent., so that it costs nearly as much to burn the lamp when old, at reduced candle-power, as when new.

Curve *C* combines the results shown in curves *A* and *B*, and shows the increase in watts per candle-power of light actually given by the lamp during its life, again taking power at the start as the unit. This curve shows that a lamp requires about 126 per cent. at 400, 157 per cent. at 800, and 167 per cent. at 1200 hours of the power taken by it at the start, so that for actual light received from the lamp, about 1.67 times as much per candle must be paid at twelve hundred hours as at first. To save the trouble of estimating distances on perpendicular lines at points intersected by curves *A*, *B* and *C*, the following table is given showing percentages of initial candle-power, of initial power, or watts, and of initial watts per candle for these three curves, respectively, corresponding to each one hundred hours of lamp-life from one hundred to twelve hundred:—

Hours Burned.	100	200	300	400	500	600	700	800	900	1000	1000	1200
A Per cent of initial candle-power	95	90	84	78	73	68	64	62	57	56	55	55
B Per cent of initial watts required	101	102	100	98	97	96	95	94	93	92	91	91
C Per cent of initial watts per candle-power	107	114	119	126	134	140	150	157	162	165	167	167



CURVES OF CANDLE-POWER, WATTS, AND WATTS PER CANDLE

With the wide variations in the initial power required by lamps of the same lighting capacity at the start, the rapid fall in light and the marked increase in cost per candle of light delivered during the life of the lamps, it is evident that the cost of incandescent lighting may be greatly varied by proper or improper selection of lamps for a desired effect. To point out the main considerations which determine the selection of incandescent lamps for a given amount of light at the least cost, is the object of this paper. It has been ably shown by others that, with any given rate for power, there is a period in the life of an incandescent lamp at which the total light given off has cost less per candle than at any earlier or subsequent time; but this touches only a part of the questions involved in lamp selection. The user wants light which may be measured in candles, though he does not usually care to go to the expense and trouble of having such measurements made; but he must buy lamps which vary in candle-power as they burn and require different amounts of power for the same light-giving quality, according to the kind selected.

Though lamps are spoken of as of definite candle-power, these powers are definite only so long as the lamp remains unused, and a 16-candle lamp when new may be a 10 or 12-candle lamp the next month, after it has begun to burn. Incandescent lamps can be

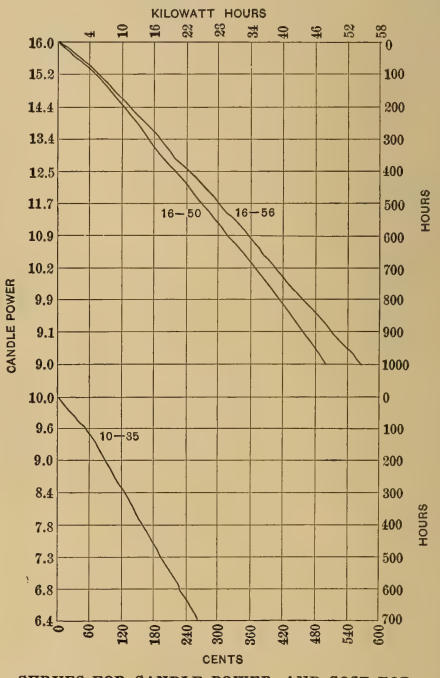
had from any of the regular makers in a variety of candle-powers, as 8, 10, 16, 20 and 32 candles, the power in watts required by each of these lamps varying nearly as the rated candles, though the 8 and 10-candle sizes take a little more power in proportion than the most efficient lamps of larger power.

As all lamps drop rapidly in candle-power, it should be considered whether lamps of comparatively large nominal power, burned to the breaking point, or lamps of less rated candles, burned for a much shorter period, will give equal results at the less cost. When comparing results to be had with lamps of different nominal powers, it should be held in mind that the average candle-power of a lamp during its life is of little or no importance, since a more powerful light than is required at one time by no means compensates for less light than is required at another, but, on the contrary, makes conditions at the time of poor light even more unsatisfactory.

For any given work or location the minimum amount of light suitable for the purpose should be decided on and a lamp then selected to furnish not less than this required light during the time it is to burn for the least sum, considering consumption of power and first cost of lamps. Again, lamps which consume the smaller numbers of watts per candle do not burn as long as those that require more power, and it should be decided whether the saving in power for a lamp burned out before it reaches the minimum required candles will compensate for the more frequent renewals over a less efficient lamp. Nominal 16-candle lamps are much more commonly used than any others in the United States, while in Great Britain a nominal 10-candle lamp is generally employed, and such a lamp is gradually finding favour in the United States.

The nominal 16-candle lamps, as regularly made, require fifty, fifty-six and sixty-four watts at the start, while the 10-candle lamps consume thirty-five and forty watts when first connected up. The 16-candle lamps, taking fifty-six and sixty-four watts, will usually burn from one thousand to twelve hundred hours, and the fifty-watt lamps will burn several hundred hours less.

The 10-candle, 40-watt lamp may be expected to burn as long as the 16-candle, 56-watt lamp, and the 10-candle, 35-watt lamp for about the same time as the 16-candle, 50-watt lamp. To aid in lamp selection a diagram has been



CURVES FOR CANDLE-POWER AND COST FOR INCANDESCENT LAMPS

constructed containing curves of candle-power and total cost at various stages of life for 16-candle, 50-watt lamps, 16-candle, 56-watt lamps, and 10-candle, 35-watt lamps. Conclusions arrived at from these curves can be applied to lamps of other candle-powers and watt consumption.

In this diagram of candle-powers and costs, given on the opposite page, the lower horizontal line is marked with the amounts in cents, which represent the total costs of lamps and power consumed up to various points in lamp life. The top horizontal line is marked with the numbers of thousand watt-hours, or kilowatt-hours, corresponding to the costs in cents on the lower horizontal

line, minus the cost of one lamp in each case.

The cost of all lamps is taken at twenty cents each, this being the standard market price in the United States for the best known lamps from 8 to 20 candle-power and of the rates of power consumption named. As the price of electric energy, based on kilowatt-hours, varies much between different places and even between different users in the same city when supplied from central stations, it is impossible to name any standard price for electric service; but the cost figures and curves are based on a price of ten cents per kilowatt-hour, which is probably rather below than above the average charge in the United States.

The figures along the left perpendicular line indicate the candles of light given by the several lamps at periods after starting, shown by the hours marked along the right-hand perpendicular line. This diagram, therefore, shows the candles given by, and the total cost of, either of the lamps for which curves are drawn at any period after starting.

Periods along the right-hand vertical line are indicated each one hundred hours from the start up to one thousand hours for the 16-candle lamps, and to seven hundred hours for the 10-candle lamp, and the curves indicate that the lamps should be put out of use before these maximum periods are reached should they not burn out.

In order to save time in estimating the fractional parts of spaces on horizontal lines, to secure total cost at the end of any hundred hours, the following table is given for the three lamps indicated by curves:—

LAMP.	100	200	300	400	500	600	700	800	900	1000	HOURS BURNED
16—56	76	133	190	246	300	355	408	461	513	564	Total cost, cts.
16—50	70	121	172	221	270	319	367	414	460	506	"
10—35	55	91	126	161	195	229	262	----	----	----	"

Consider, first, the relative advantages of the 16-candle, 56-watt and the 16-candle, 50-watt lamps The curves for these two lamps both start at the upper left-hand corner, marked 16, the nominal candles given by each lamp, but at once move apart, owing to the larger amount of energy consumed by the 56-watt lamp, so that at the end of 400 hours the total cost of the 56-watt lamp is 246 cents, while that for the 50-watt lamp is only 221 cents, making a difference of 25 cents. As the cost of a new lamp is only 20 cents, it would be cheaper to use the 50-watt lamps, even though they burned out every 400 hours on the average. The main argument against the 50-watt, 16-candle lamp is that it burns out quicker than the 56-watt lamp; but as the 50-watt lamp will certainly burn more than 400 hours on the average, this argument has no force, and the 50-watt lamp should at least be used in all cases where from 10 to 16 candle-power is required, unless the cost of energy is much lower than 10 cents per kilowatt-hour, and provided the regulation of electric pressure at the lamp terminals is fairly good. In explanation of this last proviso it may be said that, with large variation in pressure at lamp terminals, the life of the more efficient lamp is shortened more than in the case of those less efficient. The remedy for this variation of electric pressure is to be found in proper proportion of the electric circuits, and so is outside the scope of the present article.

The next problem of lamp selection is to decide whether a nominal 10 or 16-candle lamp will furnish not less than the minimum light required in a given case, at the lesser cost. As shown by the drop in candle-power from 16, at the start, to 9, at the end of 1000 hours, the lowest number of candles given by a lamp depends on the length of time it is burned, so that the 10-candle lamp may be burned for a short time without falling below the minimum point of light reached by the 16-candle lamp in a much longer time. It is a common practice in many places to allow lamps in unimportant places to burn until they give out, which, for the average 56-watt lamp, may be anywhere from 1000 to 2000 hours. Again, in all save the

most important locations, lamps are frequently burned as much as 1000 hours before renewal, thus falling to 9 candles in case of the common 16-candle lamp.

Compare, now, the cost per lamp-hour of not less than 9 candle-power from the 16-candle, 56-watt and the 10-candle, 35-watt lamp. The 16 candle lamp falls to 9 candles at the end of 1000 hours, and the total cost of lamp and kilowatt-hours at the end of this period is 564 cents, making the average cost per lamp-hour for the period 0.564 cents. Turning, now, to the nominal 10-candle lamp, which burns 200 hours before reaching 9 candle-power, its total cost during that period is found to be 91 cents, giving an average cost per lamp-hour of 0.455 cents; so that, where 9 candles of light are sufficient it will cost 20 per cent. more to use the nominal 16-candle lamp than the nominal 10-candle lamp, renewing the first at the end of each 1000 hours and the latter every 200 hours.

If less than 9 candles of light will suffice in cases where the nominal 16-candle lamp is commonly burned between one and two thousand hours, the nominal 10-candle lamp will effect a still greater saving, as where about 7 candles of light are enough, corresponding to 600 hours of its life at a total cost of 229 cents, or 0.381 cents per lamp-hour.

For this last case the nominal 16-candle lamp costs nearly 50 per cent. more than the 10-candle lamp for the same minimum number of candles. For all power rates greater than 10 cents per kilowatt-hour, the advantages above pointed out for high-efficiency lamps and for lamps burned near their initial or nominal candles, are increased, while in cases of very low power cost, as in some isolated plants, these advantages are diminished in amount. With any given cost of electric energy curves may be readily constructed on the above principles to show the most economical efficiency and lamp life, and also the best nominal lamp for that particular case.

The selection of incandescent lamps by the above methods for a large plant will insure a considerable yearly saving, even where electric energy is cheap, and a large saving where the usual rates are charged.

As the facts pointed out become more generally appreciated by users, the demand for lamps of high efficiency and for lamps of low nominal candle-power may be expected to increase.

MODERN MACHINE GUNS

Rifle Calibre

By William Ledyard Cathcart

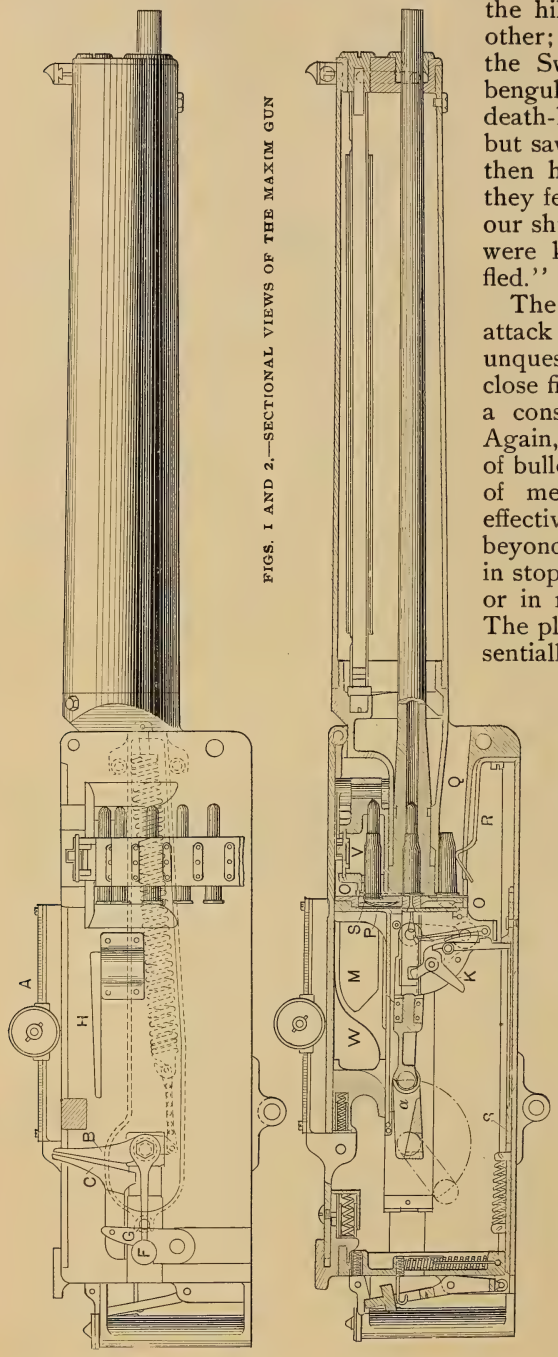
"IN my opinion, machine guns, if properly worked, would decide the fate of a campaign, and would be equally useful, ashore or afloat." So wrote Lord Charles Beresford, in describing the action of this arm at Alexandria in 1882, when its effect upon the wild mobs of fanatics was extraordinary. Early after the bombardment, the city was held by a British naval brigade of but 400 men, while Arabi, with 9000 regulars, was only nine miles away. He did not attack, because, as an Egyptian officer, later, said:—"No army could face machines which pumped lead."

There are two distinct types of the modern machine-gun of rifle calibre,—the single-barrel automatic, in which the energy of recoil, or of a portion of the powder-gases, maintains a constant fire after the first shot is discharged by hand, and the multi-barrel type, in which from two to ten barrels are grouped together, the operations of loading and firing them being performed through the simple revolution of a hand-crank. The rate of fire, even from single-barrel guns, has reached 700 shots per minute, and with the multi-barrel type, 1200.

There is no more deadly weapon

MAXIM GUNS ON TRICYCLE MOUNTING

than this arm, when it is skilfully handled against masses of troops within its range, either in steady aim, or, if pivoted, swept slowly through an arc of train. "A buzz saw of death," says one observer of its work; "it scoured the hills like a steam-hose," says another; "the devil that spits bullets," the Swazis named it; and one of Lobengula's fighting indunas describes its death-hail thus:—"I led my men on, but saw them falling like cut corn. We then halted, knelt, and fired; but still they fell. We lay down, protected by our shields; but most of the remainder were killed. So I crawled away and fled."



FIGS. 1 AND 2.—SECTIONAL VIEWS OF THE MAXIM GUN

The place of the machine-gun in the attack seems still undetermined. It is unquestionably an aid to infantry in close fighting, since, under such escort, a constant fire can be maintained. Again, in high-angle firing, a hailstorm of bullets can be rained upon the heads of men behind intrenchments. Its effectiveness in defence, however, is beyond doubt. Nothing can equal it in stopping the rush of desperate men or in reinforcing the fire of infantry. The place of the arm, therefore, is essentially in the reserve, as a gun of position. Of the several kinds of machine guns brought out, the Maxim, popularly is, perhaps, best known, by name at least, and it may not be inapropos, therefore, to consider this first in the following series of descriptions.

THE MAXIM GUN.

The cardinal principle of this single-barreled arm is the utilisation of the recoil in the automatic charging and firing of the gun. The recoiling portion is the barrel with its rearward extension, containing the lock and its connected parts; the non-recoiling section consists of the gun-case and water-jacket, which are dove-tailed together. The barrel is of the ordinary rifle type, but having a breech-sleeve on which is fixed the extension, consisting of two vertical steel plates. The water-jacket is of gun-metal; surrounds the barrel; has apertures, closed in action, for receiving and

drawing off water; and a further opening, for the escape of steam, so connected with suitable tubing as to permit the escape of steam, but not of water, when the gun is elevated or depressed. At the ends of the jacket the barrel passes through stuffing boxes.

The lock differs little from that of an ordinary pistol. With its attached mechanism it is shown, in various positions, in Figs. 3, 4, 5, and 6. The lock is pivotally secured to the connecting rod of a crank, the shaft of the latter having a handle, marked *F* (Fig 1) and the crank a curved arm, *B*. To the lock is fitted a vertically sliding carrier, *D*. The trigger, *F*, is actuated by the sprung rod, *S*, the latter being operated by a lever in the rear of the gun, on the upper end of which is a double button, pressure on which retracts the rod and releases the hammer and firing pin. The mainspring, with its action on the trigger and striker, is shown in Figs. 5 and 6.

On the right side of the gun-case there is a fixed resistance-piece, *C*, for engaging, in recoil, the crank-arm, *B*. On the left side, there is fitted a strong spiral spring to bring back the barrel after recoil, and to work the crank. The rear end of the spring is connected by a chain and fusee to the crank-shaft, and the forward end is attached to the gun-case. Cartridges are supplied from a belt which passes, from right to left, through the feed-box on the top of the gun, as shown in Figs. 7 and 8. Within the box there are two movable and two stationary pawls. The former are so connected by a lever to the barrel that the latter, in recoil, moves them from left to right. By means of a spring, they engage the next cartridge in the belt, and thus the cartridges move on automatically toward the chamber. When, after recoil, the barrel returns, the pawls place the cartridge, still in the belt, immediately above the chamber.

A BATTERY OF SIXTY-FIVE MAXIMS

The gun being in the position of "commence firing," *i. e.*, the first loading having been effected, the action of the mechanism is described by Mr. Maxim himself, as follows:—

"Fig. 2 shows the gun in the posi-

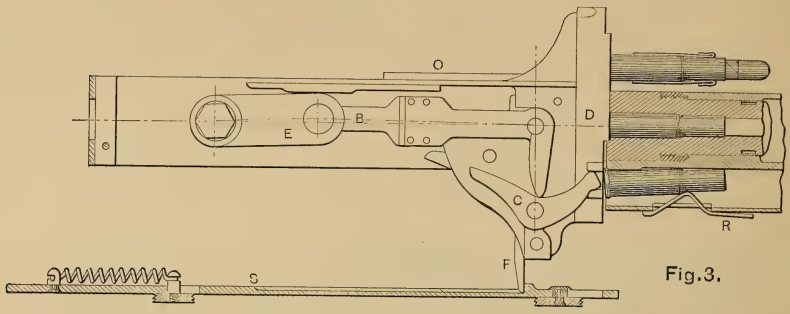


Fig.3.

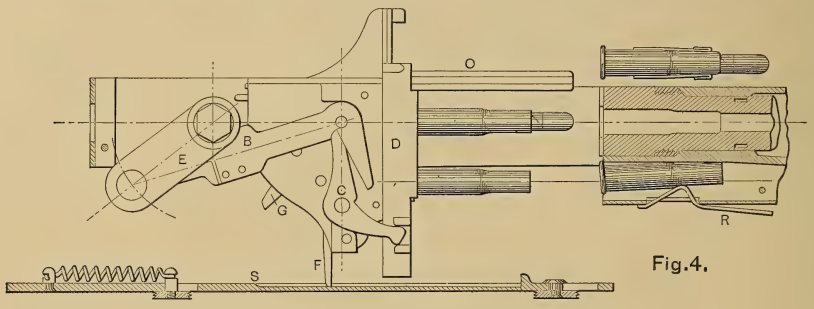


Fig.4.

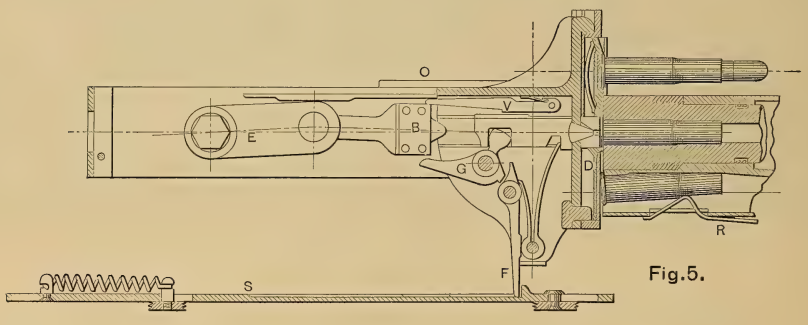


Fig.5.

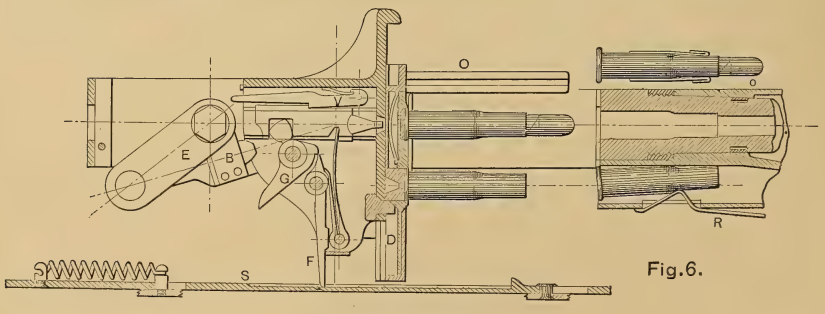


Fig.6.

MAXIM GUN—DETAILS

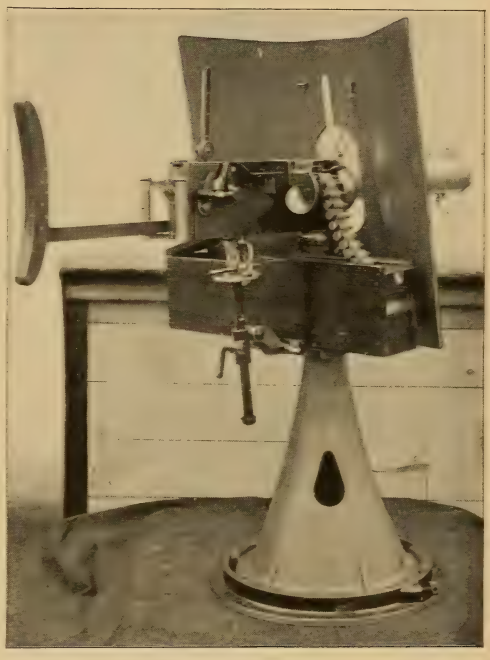
tion referred to, except that there is no empty case in the ejecting tube, *Q*. It will be observed that the breech is closed by the lock, which is held in position by the connecting rod of the crank, which latter is above the horizontal, therefore, the breech cannot be opened but by the turning down of the crank, which the pressure caused by the explosion of the cartridge has no tendency to do. It will be observed, further, that the base of the cartridge in the barrel is seized by the carrier and also that of the first cartridge in the belt.

"The gun is fired by pressing the firing button in the rear, which draws back the rod, *S*, and releases the striker. On the explosion of the cartridge, the barrel and the gear connected therewith recoil the distance of about one inch. During the recoil the crank arm, *B*, comes in contact with the resistance-piece, *C*, and throws over the crank, bringing the end of the crank-handle, *F*, on the spring-buffer, *H*. The curve on the arm, *B*, is so arranged that the crank gets an accelerated movement, by which the lock, which is connected to the crank, *E*, by the rod, *B*, is thrown back clear of the breech sufficiently far to extract, by means of the carrier, *D*, the empty case from the chamber and the fresh cartridge from the belt.

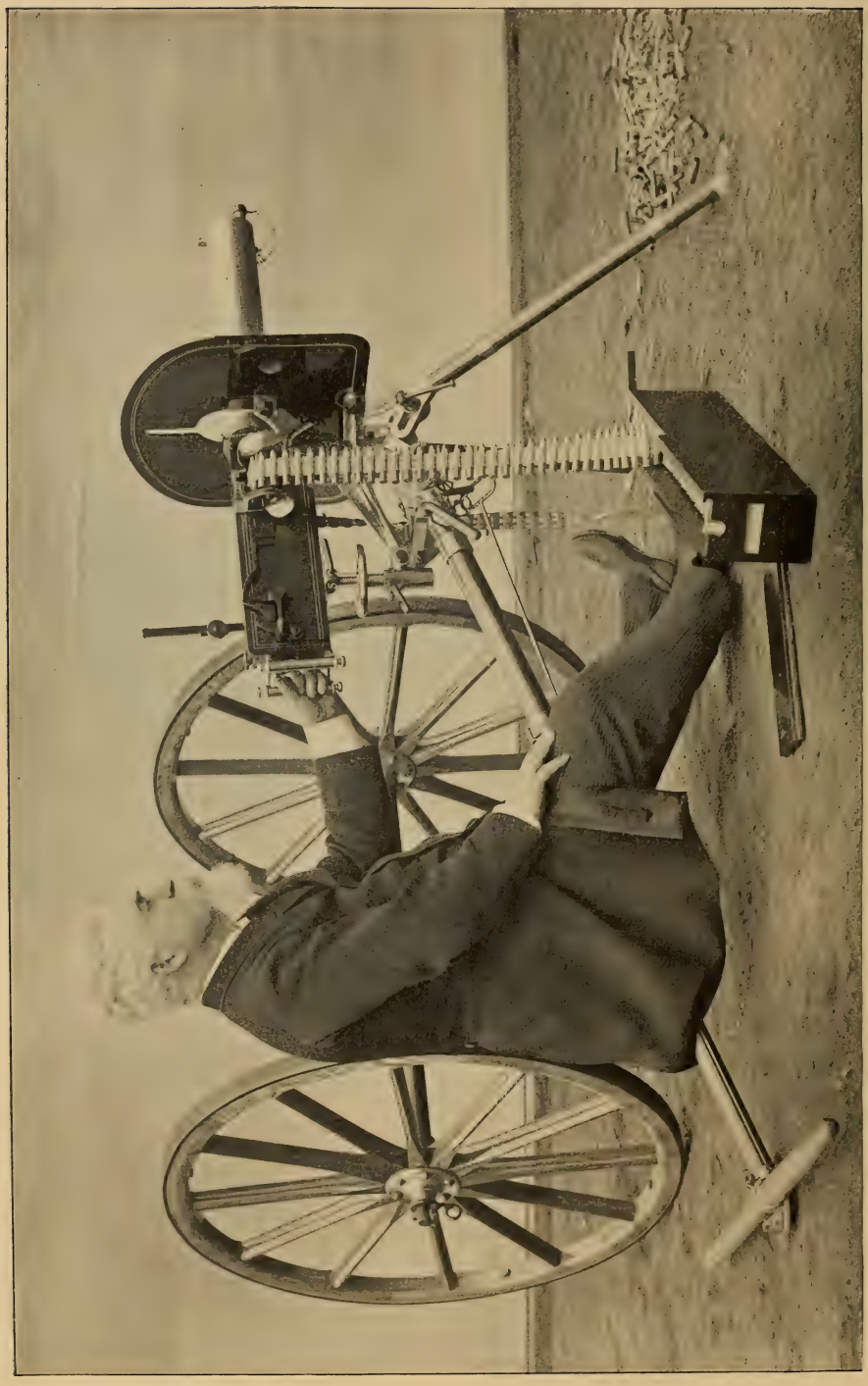
"The turning of the crank winds the chain attached to the spiral spring around the fusee, thus extending the spring. As the lock goes backward, the carrier *D*, is pressed down by the spring, *W*, and, when in its lowest position, the new cartridge is opposite the barrel and the empty case opposite the ejecting tube, *Q*. Figs. 4 and 6 show the parts, in the positions referred to. The extent of the downward motion of the carrier is regulated by means of a projection upon which it rests, when in its lowest position. In order to hold the cartridges firmly, the carrier is fitted with grooves and with pieces which are pressed forward by springs; the pieces have recesses the exact diameter of the base of the cartridges, while the grooves extend two-thirds down the carrier.

"The action of the spiral spring now brings back the barrel and its extension to their normal position; it also unwinds the chain from the fusee, thus turning the crank into its normal position, which brings the lock forward; the returning of the crank is made quicker by the reaction of the buffer spring, *H*, acting on the end of the crank handle, *F*. As the lock moves forward, it pushes the new cartridge into the barrel and the empty case into the ejecting-tube. During the last one-sixteenth of an inch of the forward travel of the lock the carrier, *D*, is raised by the carrier levers, *C*, which are acted on by the lugs on the forward end of the connecting rod. When the carrier is in its highest position it is retained there by means of a spring, which insures the centre of the base of the cartridge being opposite the striker.

"In rising, the carrier, being only grooved for two-thirds of its length, releases the empty case, which remains in



A MAXIM NAVAL GUN



SPECIAL AUTOMATIC MAXIM GUN, MADE FOR THE SULTAN OF TURKEY; 770 SHOTS A MINUTE

the ejecting-tube, *Q*, held there by the spring, *R*, so that it cannot fall back into the case when the gun is elevated above the horizontal; the carrier also grips the base of the fresh cartridge in

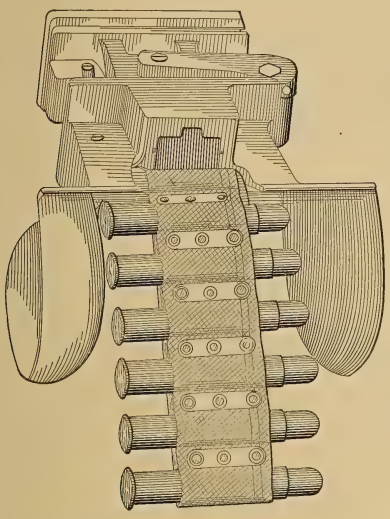


FIG. 7.—FEED MECHANISM OF MAXIM GUN

the belt. The extent of the upward movement of the carrier is regulated by a projection on the lock and by the lid of the gun-case. In Fig. 1 there will be seen a piece, marked *G*, on the right side of the gun-case, in the rear; this piece is capable of receiving a small

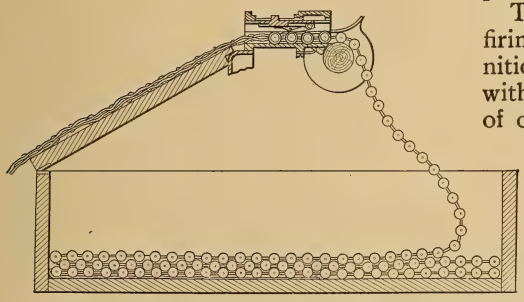


FIG. 8.—ANOTHER MAXIM FEED DETAIL

rotary movement and serves to prevent the crank-handle from rebounding on the crank going forward.

"As the lock is brought away from the breech by the action of the crank, the connecting rod, *B*, throws down the hammer, *G*, thereby pulling back the striker and compressing the main spring. When the hammer is down, in the position shown in Fig. 6, the main spring causes the short arm of the trigger to engage under the lug of the hammer, and thus the lock is cocked and cannot act until the trigger is pulled clear of the lug on the hammer. To insure the breech being secured before the lock can act, there is a safety sear, *V*, which, as the striker is drawn back by the action of the hammer, engages in the upper part. The striker, therefore, cannot move forward until this sear is raised. This is effected by the connecting rod; but not until the latter is above the horizontal, or until the breech is secured. The safety sear, *V*, is pressed down by a small spring, and its action is thus made positive.

"It will be evident that, if the pressure is taken off the firing button immediately after the explosion of a cartridge, the gun will be automatically loaded and will remain ready for firing; thus single shots may be discharged; but, if the pressure is kept on the firing button, the gun will not only be loaded automatically, but also fired, the rising of the connecting rod, as the breech is secured for each round, lifting the safety-sear and thus releasing the firing pin."

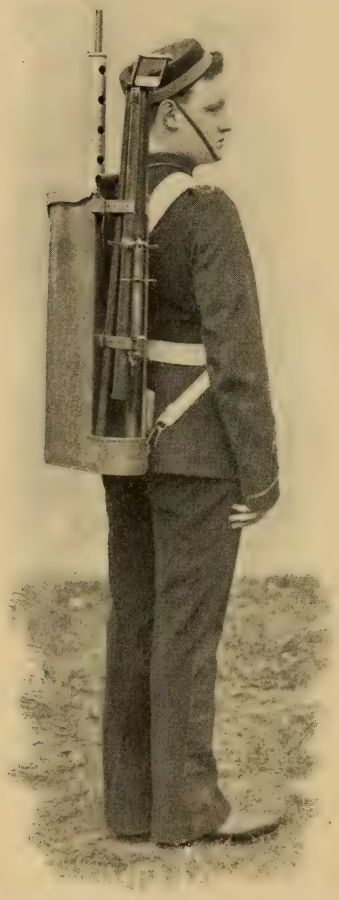
The Maxim gun can be built for firing any description of rifle ammunition. The rapidity of fire varies with the energy of recoil and length of cartridge. From 600 to 650 rounds per minute are given as its average speed, although, it is said, 750 rounds have been obtained with a short, energetic cartridge. The mechanism is so arranged that the breech is not opened until the bullet has left the muzzle, thus giving time for full combustion of the charge and avoiding the escape of gas to the rear.

The weight of the standard rifle-calibre gun is 54 pounds, while the weights of the various mountings, complete, without ammuni-

tion and ammunition boxes, are as follows:—

	Cwts.	Qrs.	Lbs.
Cavalary carriage	9	2	11
Infantry "	5	2	25
Tripod,			60
Naval mounting, cone and H. D. ring	1	3	8¼
" landing carriage,	5	1	19¾
Parapet mounting,	1	2	12

A lighter pattern of this gun, weighing 25 pounds, has recently been perfected. The whole equipment weighs 57 pounds, and can be carried by a trooper in a cavalry boot or by an infantryman in a knapsack.



MAXIM'S CAVALRY GUN; WEIGHT, 30 LBS.; 700 SHOTS PER MINUTE

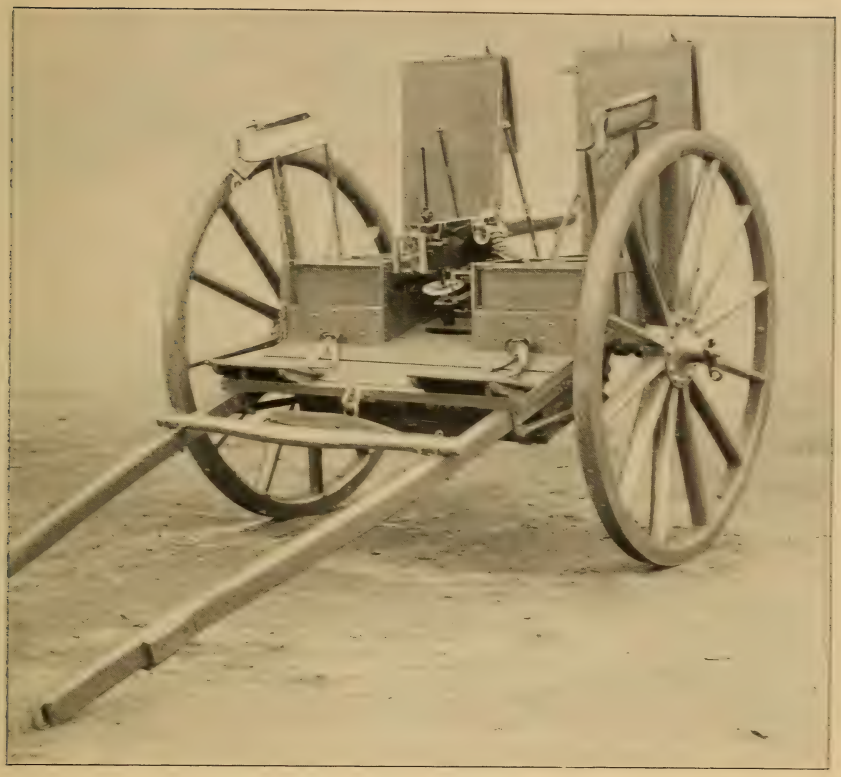
THE GATLING MACHINE GUN.

This formidable weapon was invented by Dr. Richard Jordan Gatling in 1861. It has done good service in one of the latest battles of our time, the assault on Santiago de Cuba during the late war between the United States and Spain, where, from some of these guns, a continuous hail of projectiles swept along the tops of parts of the Spanish trenches. The essential parts of the arm are shown in longitudinal elevation in Fig. 9. The gun is composed of a series of small-arm rifle barrels (five, six, or ten, the last in the United States Army type), grouped symmetrically about a central shaft. Each barrel has its corresponding lock.

The shaft constitutes the axis of revolution of the system, and the turning of the crank, in the rear, rotates the barrels with their locks and the inner breech or carrier blocks, thus loading and firing the gun and extracting and ejecting the empty cartridge-shells. In its revolution there is given to each lock a forward and rearward motion; the forward stroke places the cartridge in the chamber, closes the breech, and releases the firing pin, thus discharging the gun; the rearward motion extracts and ejects the empty cartridge shell and returns the lock to its original position.

In Fig. 10 there is shown, in development, the cam-groove, which produces the reciprocating motion, with also the firing mechanism. The locks rest in grooves on the outer surface of the lock-cylinder, and lugs formed on them engage the groove of the cam-cylinder, secured within the casing of the gun at its rear end. On the interior surface of the latter cylinder there are two helicoidal grooves, united, at the forward end, by a straight recoil-plate, or shoulder, the grooves serving to give a reciprocating motion to the locks, in succession pushing the cartridges into the chamber and withdrawing the empty shells, while the intervening recoil-plate acts to support the lock while the cartridge is being fired.

The cocking-rib is a small arc-plate, so mounted in the rear of the cam-groove as to engage a knob on the rear end of each firing pin, as the system rotates, and hold it back while the cam-groove drives the lock-bolt forward,



A MAXIM GUN WITH INFANTRY CARRIAGE

thus compressing the main or firing spring. When the cartridge is seated and backed up by the lock-bolt, the further rotation of the system carries the firing pin beyond the cocking rib and discharges the gun.

The carrier-block is supported between the rear barrel-plate and the lock-cylinder. It receives the cartridges, holds them until revolved opposite, and entered into, the chambers, receives the empty shells after firing, and carries them from the time they are withdrawn by the extractor until ejected. The locks are supported in it by *T*-shaped splines. The extractor is a sprung hook, so secured in a groove in the lock that it may move sufficiently to spring over the flange of the cartridge-head when the lock-bolt engages the latter. After the cartridge is fired, a fixed steel "plough" strikes the rim of the shell and frees it from the extractor; it is then forced out by the cartridge-guard.

The gun is fed with service cartridges from the feed-cases, guide-ways, or magazines, which place the ammunition directly in the carrier-block, it being possible to so maintain the feed that a continuous firing is kept up at a rate, according to the speed of the crank, of from 600 to 1200 shots per minute.

In the illustration on page 58, the United States Army type of Gatling is shown. This is fitted with the Bruce feed. This system permits cartridges to be delivered directly to the gun from the paper boxes in which they are packed at the factory, thus dispensing with the filling of the magazines or feed-cases. The Bruce feed-case consists of a frame having, at its lower end, a single T-groove in which the head of the cartridge-case fits. Pivotally mounted above this is a double T-grooved frame, capable of vibration so that either of its grooves may form a prolongation of the single

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A GATLING GUN ON A FIELD CARRIAGE ABOARD THE U. S. S. "ENTERPRISE"

groove below. The packing box is lowered until the heads of all its cartridges are engaged, in two columns, in the double grooves. The cartridges in one row are then fed into the single guide until that row is empty, when those in the second groove are pivoted into line, this alternation being continued as long as the cartridges are fed into the double-guide grooves. Each groove holds 30 cartridges.

In the illustration on page 60, the gun is shown fitted with the Accles feed, as used in the United States Navy, the system being shown in detail in Fig. 11. This feed case is designed to give a positive feed to the gun, and is fitted especially for high-angle firing. It consists of a drum with a central bore. On the interior faces of the drum are spiral guide-ribs of four convolutions, which support the cartridge at each end. Within the drum, and journalled on its inner cylindrical surface, there is a double propeller disc, which, by radial slots, engages the cartridges and by projecting lugs meshes with the carrier-block, so that the rotation of the latter by the gun-crank revolves the propeller-disc. A spiral column of cartridges is thus continuously moved forward, each radial groove in the disc feeding a cartridge in succession into the hopper and thence into the carrier-block. The feed-case is filled by dropping in the cartridges through the peripheral mouth, while the propeller-disc is being revolved by hand.

The Gatling has the endurance of the multi-barrel type, there being an absence of the tendency to overheating, owing to the number of barrels used, the use of but one barrel at a time, and the rotary motion. In a trial for endurance, held before a naval board, over 100,000 cartridges were fired, of which over 65,000 were discharged without stopping to clean the barrels. The disablement of a lock or barrel does not make the gun unserviceable. The disabled parts may be withdrawn

and the gun will work on with the remainder, it being possible to fire the gun while a single lock and its barrel are in good condition. It can be fired at all angles of elevation and depression, and, with the positive feed, can deliver grains; muzzle-velocity, 2000 feet per second; penetration, 48 inches.

THE ACCLES GUN.

The Accles machine gun is a modification of the Gatling type of this arm,

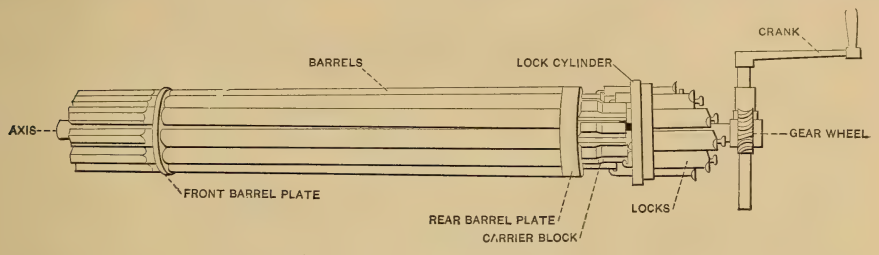


FIG. 9.—A 10-BARREL GATLING GUN

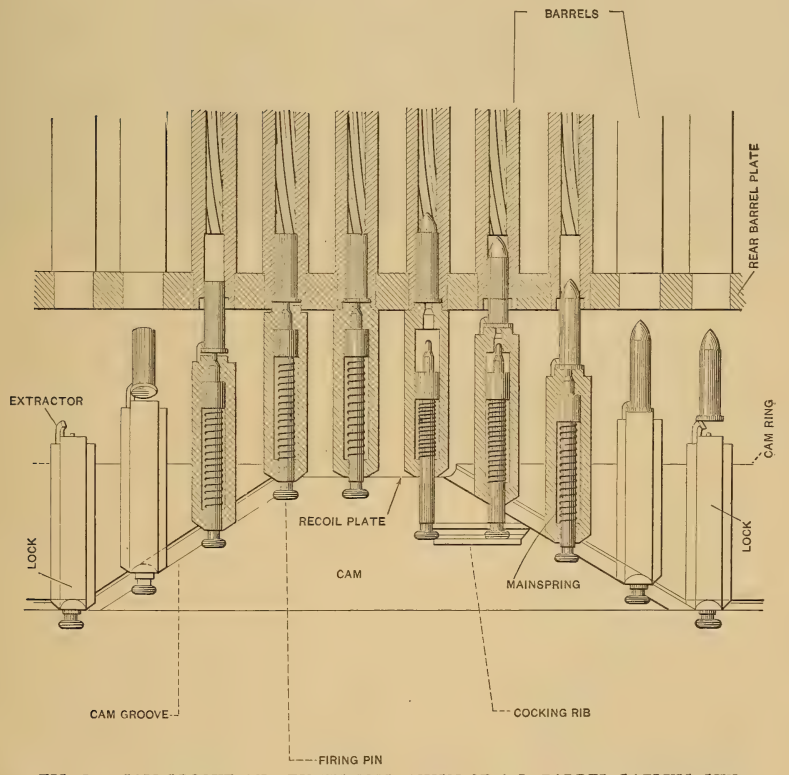


FIG. 10.—CAM-GROOVE AND FIRING MECHANISM OF A 10-BARREL GATLING GUN

bullets behind intrenchments, on the roofs of buildings, etc. The following particulars refer to the standard Gatling gun, U. S. Army model:—

Bore, 0.30; length of barrel, 32 inches; weight of bullet, 220 grains; powder charge (smokeless), 38 to 42 —the most important of the changes being that the shaft of the lever which actuates the gun is concentric with the trunnions, thus, it is claimed, avoiding, in rapid working, vibration which affects the accuracy of fire. The gun is shown in various sections and elevations in

A GATLING GUN WITH BRUCE FEED SYSTEM. UNITED STATES ARMY TYPE

Figs. 12 and 14, and in Fig. 13, transverse sections of the feed mechanism in detail are given.

The arm is built with five, six, eight, or ten barrels, *a*, (Fig. 12), as desired, the latter being grouped circumferentially about, and revolving with, a central spindle, *b*. Each barrel carries with it, in its motion, its corresponding lock, *x*, which lock engages the camways of a stationary, actuating cam, *c*, fixed in the rear end of the gun-case, the engagement and rotation of the locks and their attached parts effecting, with the feed-motion, the operations of charging, firing, and ejecting.

The gun is operated usually by a crank (Fig. 14) engaging a worm-shaft, which passes through the trunnions and carries a feathered clutch-sleeve. This is capable of engaging a corresponding clutch formed on a worm, loose on the shaft, but in engagement with a worm-wheel through which the spindle and barrels pass. The sleeve is shifted into or out of engagement through a switch, *d*, by a trigger, *e*, the latter being under the control of the man who, at the rear, aims the gun. Thus, while the crank may be turned continuously by another of the gun's crew, or, in naval mounts, by an electric motor, the barrels will revolve and the gun be fired at the will of the pointer only.

The crank may also be placed on the rear end of the spindle, when as many shots, per revolution of crank, will be fired as there are barrels. The worm-gearing is so proportioned that, when the crank is at the side, one-third of this number is fired. Since aiming is impossible with the crank revolving in the rear, this method should be used only when it is necessary to pour a very rapid fire into a given point. The locks are arranged at their rear ends to fit the grooves of the actuating cam which reciprocates them. The cam is divided into four parts, viz., receiving, loading, firing, and extracting.

Ammunition is supplied in light cardboard packets holding from 25 to 50

cartridges each, a cartridge lying in each groove of a fluted tin strip within the packet. The feeder through which the cartridges are fed is placed on the left side of the gun. At its top is a feed-wheels. The object of this is to insure that the cartridges shall be in position before the mechanism moves, thus avoiding any jam in feeding.

The lock is a straight piece of steel,

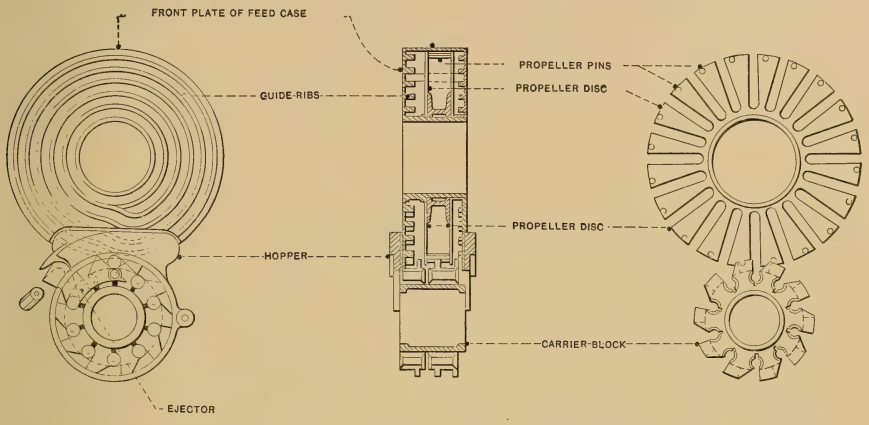


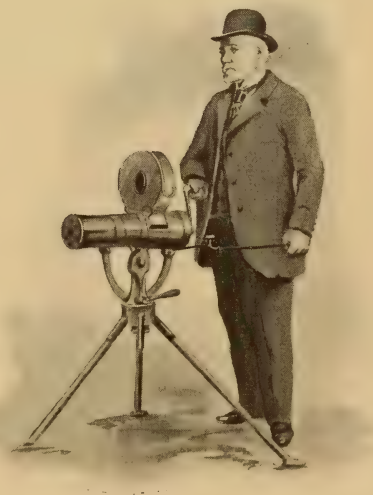
FIG. 11.—ACCLES FEED FOR A GATLING GUN

narrow opening in which the packet is entered. At the bottom of the opening are two small wheels, with projecting teeth, into which the first cartridge enters, and, at the same moment, the body of the cartridge presses down a small lever, *f* (Fig. 13), which moves a clutch, *g*, into gear with the driving wheel, *k*.

The latter is continuously rotated by the turning of the gun, and so puts the two feeding wheels into action, drawing the cartridges out of the packets by means of the fluted tin strip, and bringing each cartridge evenly in line with the teeth of the feeding wheels. The cartridges are carried around, out of the tin strips in a groove on each side of the feeder, and are forced into the grooves in the cartridge receiver of the gun. The tin strips pass through the feeder and drop to the ground, the empty packet being thrown out from the feeder by the ejector.

The two feeding wheels do not revolve until a cartridge has been placed in their teeth and the lever pressed down, pushing the clutch into gear. The clutch is thus engaged until the last cartridge has passed out of the feed wheels, when the lever flies up, disengaging the clutch, and stopping the

arranged at the rear to fit the grooves of the actuating cam and having a *T*-projection on the under side to guide and hold it in its stroke along the grooves in the guide-cylinder and receiver. Through its centre there passes the firing pin, *m* (Fig. 12), of round steel, with, at the rear, a flanged head to engage the cocking device, *n*. The pin is given striking force by a spiral spring, *S*, acting between a stationary

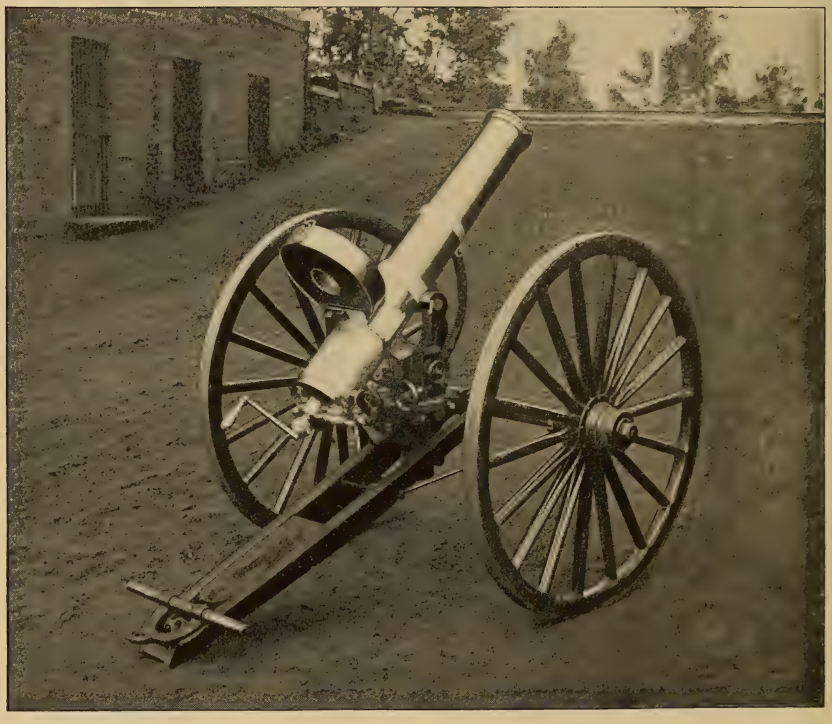


DR. GATLING WORKING ONE OF HIS GUNS

bushing in the lock and a collar on the pin.

The extractor, *p*, is fitted to the under side of the lock and partly in the *T*-way. Its rear end is round, and its front end is provided with a wedge-shaped projection which enters a similarly formed notch in the front end of the lock. By means of the wedge the extractor is drawn tightly against the head of the cartridge, as the lock moves rearward. When the gun is operated, the extractor slides along in the receiver-groove, which is deeper at the front end, so that the extractor can drop down and pass over the rim of the cartridge. When, after firing, the lock is drawn to the rear, the base of the extractor meets an incline, *r*, in the bottom of the receiver-groove, which forces the extractor up against the cartridge-head.

When the gun is in operation, the first section of the actuating cam, *A*, which is flat, keeps the lock back until the cartridge has passed from the feeder into the receiver-groove in front of the lock. The second section is an inclined groove, along which the locks are forced, thus pushing the cartridges forward into the barrel. When two-thirds of this groove has been traversed, the firing pin comes in contact with the cocking device and is held back while the lock is carried forward.



GATLING GUN WITH POSITIVE ACCLES FEED FOR HIGH-ANGLE FIRING

In passing into the third section, the lock arrives at the firing surface of the camway. At this point the cartridge is driven home, being supported by the lock abutting on the firing surface. The firing pin now slips off the cocking device and discharges the cartridge. The firing surface is flat, so that the cartridge is held tightly in the chamber during one-fourth of the revolution of the gun, thus giving a long "dwell" in case of a hang-fire.

As each lock arrives at the end of the

firing surface, it passes into the fourth section, or extracting groove of the cam, which draws the lock to the rear, and, with it, the empty cartridge-case, the latter being withdrawn from the barrel by the extractor. The cartridge-case comes in contact with two curved ejector points, *N* (Fig. 13), which dip into two circular grooves cut in the receiver. These points pass under the case, roll it out of the receiver-grooves, and eject it from the gun. In the meantime, the empty receiver-groove has passed on to take another cartridge from the feeder.

In action five cartridges (in a 6-barrel gun) are in the various stages of loading, firing, and extracting; and, although 1800 shots per minute can be discharged, only one shot is fired at a time. The recoil is taken up, through the lock, on the firing surface of the cam; the forward movement of the barrels is resisted by a check-disc, connected to the main spindle and barrels, and pressing against a shoulder cut around the inside of the case in front of the trunnions. By means of a safety-cam the cocking device may be moved back out of action, so that the firing pins will not touch it while the gun is being operated for drill, thus preventing the undue snapping of the firing pins. The following particulars refer to the Accles gun, U. S. Army pattern, 6-barrel:—

Calibre, 0.3 inches; lengths—of barrel, 28 inches, of rifling, 25.7 inches; number of grooves, 4; depth, .004 inches; twist, one turn in 10 inches; weight of gun, complete, 150 pounds; elevation, extreme, 50 degrees; depression, extreme, 50 degrees; rate of fire per minute, crank at side, 360, crank at rear, 700; ammunition, U. S., .300; bullet, nickel-jacketed, weight, 220 grains; charge of powder, 40 grains; kind of powder, smokeless; initial velocity, 2000 foot-seconds; weight of Y-mounting, 26 pounds.

The guns are mounted on field carriages, parapet and embrasure mountings, and on naval mountings. Exclusive of gun and Y, the weights of various mountings are as follows:—

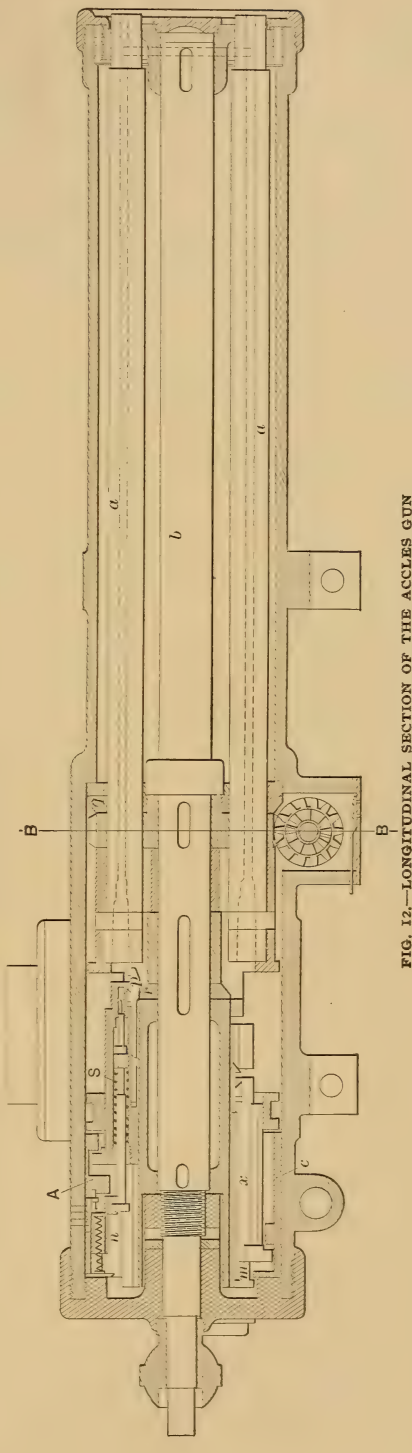


FIG. 12.—LONGITUDINAL SECTION OF THE ACCLES GUN

Rail socket and shield, 118 pounds; deck or bridge pedestal and shield, 223 pounds; top mount, shield, moving table, and base-ring, 238 pounds; boat mount, pedestal, base-ring, 66½ pounds; naval landing carriage, two-wheeled, ammunition boxes, 4000 rounds; tools and accessories, 737 pounds; limber for naval landing carriage, ammunition boxes, 8000 rounds, tools, accessories, 1152 pounds; tripod mount, 44 pounds.

THE GARDNER GUN.

The improved Gardner machine gun, as shown in vertical section and in top view, with breech-cover open, in Fig. 15, consists of two simple breech-loading rifled barrels, placed parallel to each other, about 1.4 inches apart, in a case or compartment. These two barrels are loaded, fired and relieved of shells by one revolution of the hand-crank. The working of the piece is simple. One man inserts the heads of the cartridges projecting from a feed case into the feed-guide, drawing the case from the cartridges; another man turns the crank, by which the gun is fired, and as the cartridges disappear down the feed-guide their places are supplied from another case. In this manner the firing may be made continuous.

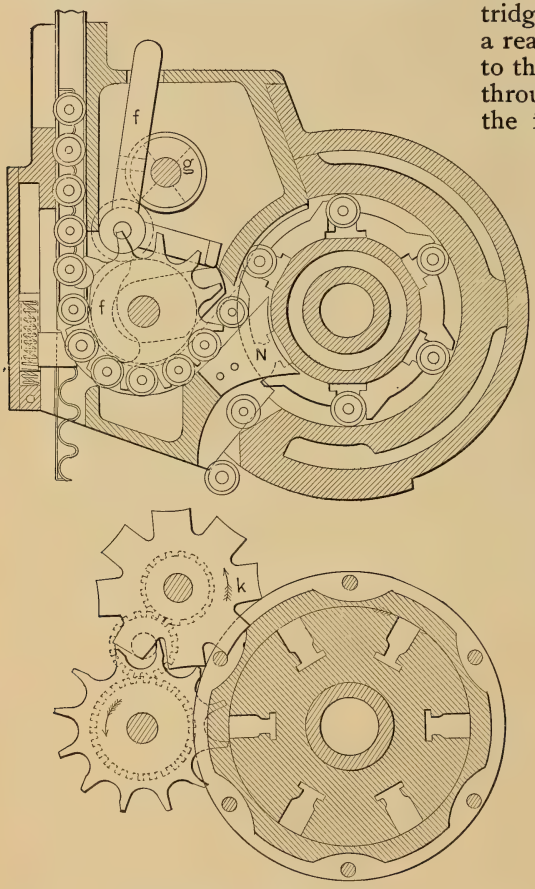


FIG. 13.— CROSS SECTION OF THE ACCLES FEED MECHANISM

The barrels are open from end to end, and chambered at the rear to admit a flanged, centre-fire metallic cartridge. They are firmly screwed into a rear barrel plate, which is pinned fast to the rear casing, and the muzzles pass through another similar plate, called the front barrel plate, which is fitted into the front of the casing and made fast with a taper pin. The rear of the casing extends from the rear barrel plate far enough to contain all the lock parts, together with the lock cam and safety stop. A swinging casing cover, hinged at the forward end, is firmly locked in position by a cascabel having a screw thread cut on its stem, which enters the rear casing, locking it. When the cover is raised, which can be quickly done after turning back the cascabel, all the working parts of the gun are fully exposed; and should an accident occur, like the bursting of cartridge heads, or derangement of locks, the trouble can be instantly discovered, and as quickly remedied.

The hand-crank which operates the gun is locked fast to the main cam, the latter being supported by journal boxes. The boxes are locked into the rear casing, and serve as a protection to the casing cover from side thrusts. The body of the lock cam has journals, or crank pins, for operating the locks, diametrically opposite each other (the firing being alternate), and eccentric enough to

give the required motion to the locks as they are moved forward and back, driving in cartridges and withdrawing shells. The outer portions of the cams are flattened to the circle of the periphery of the main cam, for

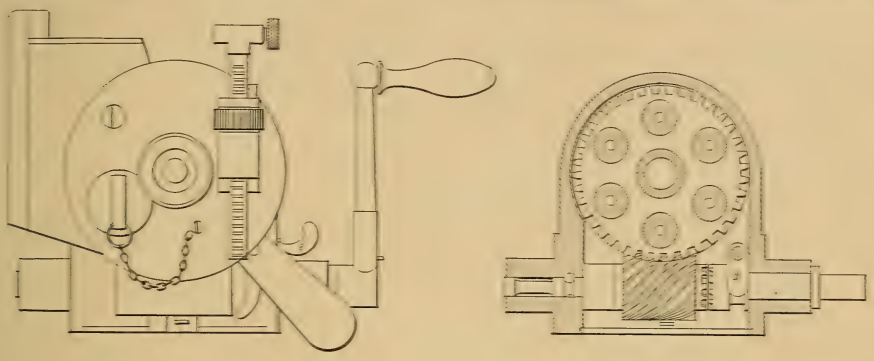


FIG. 14.—REAR ELEVATION AND SECTION OF ACCLES GUN

the purpose of holding the lock stationary, while firing, about one-fifth of a revolution of the hand-crank, allowing ample time for hang-fires.

The lock in form resembles the letter *U*, having an extension from its side which contains the firing pin, main (spiral) spring, cocking levers or spring compressors, firing pin rack, extractor, and lock head. The *U* part of the lock, which works under, and around, the cam pin, is curved at the inner front to correspond with the outer circle of the cam, the office of the curved front being to hold the lock in position for firing. The circular firing pin is flattened a portion of its length near the front end, to allow it to pass under the extractor by which it is held in position. It extends from the head of the lock through the main spring and firing pin rack, terminating in a flange or head, for locking into a sear. The sear, having the form of a bell crank, pivoted in the centre to the lock, holds the firing pin securely, and prevents it from touching the cartridge until it is released from its hold by the action of the cam when the lock is in its extreme forward position.

The cocking lever, hinged in a recess of the lock, and engaging, by means of gear teeth, with the firing pin rack, has its arm forced against the main spring compressor, thus compressing, through the medium of the firing pin rack, the main spring, and holding it tense until released by the action of the sear.

The cocking cam is located in the casing, between the locks, at the front of the lock cam. It is so arranged that it engages the arm of the cocking lever in the backward movement of the locks, thus positively withdrawing the firing pin, and at the same time forcing the head of the same over the catch of the sear.

The lock heads serve as breech plugs, and receive the recoil when the cartridges are fired. Each lock carries a hook extractor, which rides over and catches the flange of the cartridge, when the lock is forced forward, and when the lock retreats, withdraws the empty shell until it comes within reach of the ejector, by which it is positively thrown out. The shell starters have a positive movement in connection with the lock head. Should the cartridge be driven by the extractor into the barrel, to its head (as is the case when the gun is worked rapidly), before the lock is in firing position, it is forced from the chamber by the shell starter as the lock advances, and is held long enough for the extractor to engage with the head, when the lock, extractor, and cartridge are driven home together.

The ejectors, hinged to the casing, are driven by projections on the sides of the locks, which give them positive

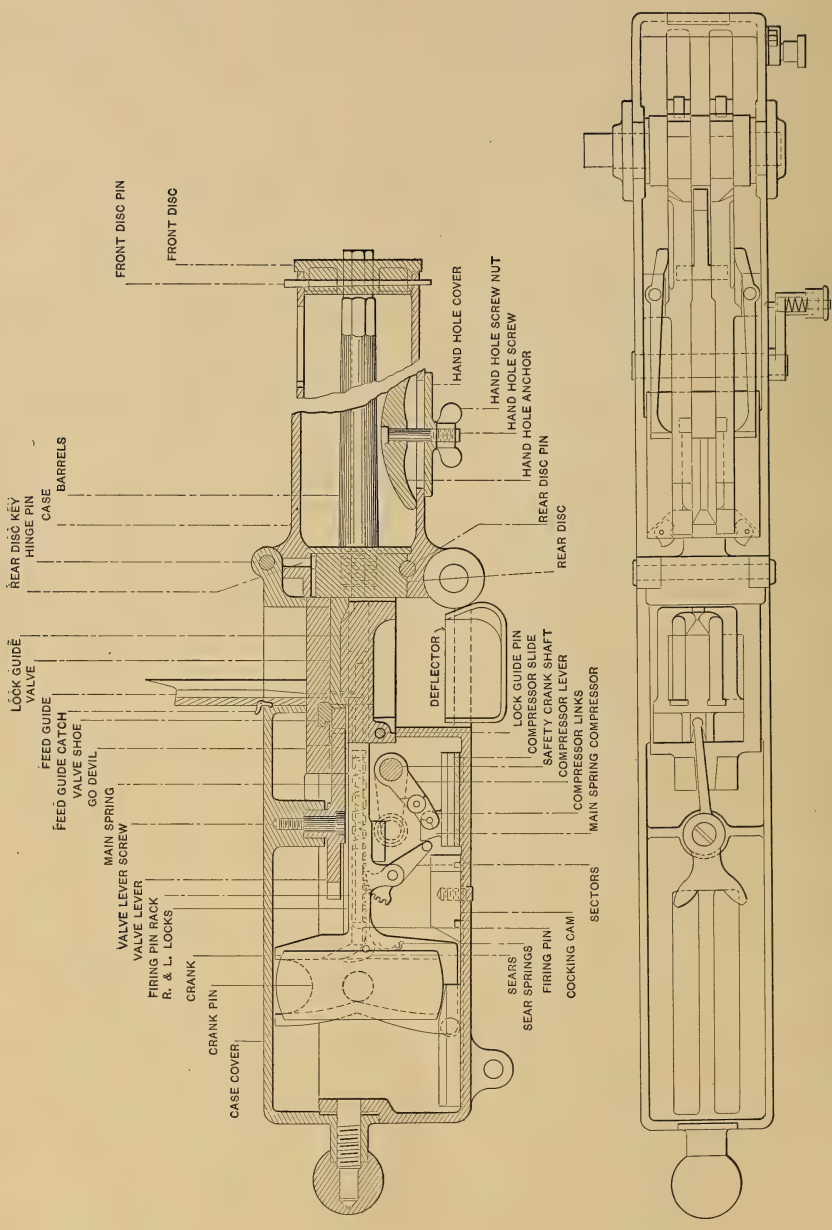


FIG. 15.—TOP VIEW AND LONGITUDINAL SECTION OF THE GARDNER GUN

movements to eject the empty shells. They also serve as stops to prevent cartridges from falling through the lock guide as they are forced down through the feed valve.

The lock guide extending across the rear casing, to which it is fastened by a pin, has two parallel semi-circular grooves, which are enlarged extensions of the chambers in the barrels. From the back part of the groove, slots large enough to freely pass the cartridges (being wider at the rear, behind the ejector, than at the front) are cut downward through the lock guide. When the extractor has drawn the shell back nearly to the extent of the throw of the cam, the ejector forces the shell through the slot, and is then in position to receive another cartridge from the feed valve. The feed valve, attached to the casing cover, has a reciprocating motion across the lock guide. It has two angular openings of the size and shape of the outline of the cartridges, which centres equidistant with the centres of the barrels. After a cartridge has dropped one-half its diameter into the valve, it is forced by the action of the latter into its true position, and held positively against the angle of the lock guide. When the valve is again moved back, the cartridge is forced downward into the lock guide, and the column of cartridges is cut off in a go-devil, which is located firmly in the casing cover above, and in line with, the lock guide.

The feed valve is driven by the feed valve lever; this also is attached to the casing cover, and is operated by the locks, using about one-fifth the stroke of the crank in its forward motion, thereby giving the valve ample time to hold both cartridge and shell down in position as they move in and out from the barrel.

The feed guide is a simple plate having two parallel *T*-grooves, extending from end to end. The upper end has a projection, with rib extending upward, for the purpose of guiding the cartridges into its mouth. The lower end is provided with a cartridge stop, which lifts all cartridges contained in the guide when it is taken out from the casing cover by which it is supported. The guide is held fast in firing position by a spring catch. It can be quickly released by drawing back the catch by pressure on its exposed arm. In placing the guide in position, the spring catch is self-acting. These operations require but one hand, leaving the other free to place the safety crank in position.

The main spring compressor is an oblong block having an angular face against which the arm of the cocking lever in the lock may engage when the locks are moved forward by the cam. It is held in position by two links which are moved by a lever that is splined to a shaft passing through the rear casing, to the outer end of which is pinned the safety crank. This crank has a stop spindle in its handle, behind the shoulder of which is a spiral spring that forces the spindle out from the arm into the stop holes, marked "Safe" and "Fire," in the rear casing.

When the safety stop is in the hole marked "Fire," the arm is in line with the barrels, the main spring compressor is thrown within reach of the cocking lever, by which the main springs are compressed, and the gun is in firing position. When the spindle is in the hole marked "Safe," the main spring compressor is carried forward out of the way of the cocking lever, and in no case can the springs be compressed while the stop is in the safety hole.

By actual test, it is found that a pressure of less than four pounds is exerted on the end of a 7½-inch crank in firing the gun. The piece can be assembled in about a minute, and taken apart in the same time. The weights of the improved Gardner gun are as follows:—

Gun, two-barreled	100 to 125 lbs.
Each additional barrel, about	10 "
Gun mount	62 "
" carriage	389 "
Caisson, with cases for 7200 cartridges	697 "
Tripod for naval gun	59 "
Spare parts, tools, etc.	8 "

THE HOTCHKISS GUN.

The Hotchkiss automatic machine gun (rifle calibre) is a single-barrel arm of the type in which a portion of the

A HOTCHKISS GUN

gases resulting from the explosion of the powder-charge is utilised in operating the breech-action and feed-mechanism; and, more particularly, of the class in which a motor-piston, in perpetual engagement with a power-accumulator, is operated by the powder-gases. After the first round is fired by hand, the operations of loading, firing, and extracting are carried on automatically, but under complete control of the gunner. The gun is shown in longitudinal section and plan in Fig. 16, the piston being retracted and breech open.

The gun consists of a single barrel, *A*, screwed into the front of the receiver, *B*, the latter encasing the mechanism and supporting the trunnions, the pistol-grip, *O*, and the shoulder-piece. Below the barrel, and parallel to it, is secured the cylinder, *C*, in communication with the bore through the port *c*, which is a few calibres distant from the muzzle. Within this cylinder, there reciprocates the piston, *F*, bearing on its extended rod or stem the sear, *f*, the cams, f^1, for operating the breech-block, and the cams, f^2, giving intermittent motion to the feed-wheel, *U*. The rearward stroke of the piston is produced by the gas-pressure after discharge, the forward stroke by the action of the helical spring, *M*, which bears against a lug depending from the piston.

The piston's movement is controlled normally by the sear, *f*, which engages the sprung trigger, *N*. If the trigger be held back, it is apparent that the reciprocation of the piston will proceed continuously, and, that, since the latter affects automatically, through the cams noted, all of the required operations, firing also will be continuous while ammunition is fed.

Depending from the piston is the finger-piece, *G*, by which the former is drawn to the rear and the gun cocked for the first shot. Pivoted to the receiver is the cocking lever, *X*, for use in starting the piston when the gas-pressure is insufficient to move the latter, owing to a cartridge-case, soft or defectively fired, sticking in the chamber. Within the feed-block framing, *T*, there is situated the sprung stop, *V*, for arresting the piston at the rear end of its stroke, independently of the trigger. There is also fitted, just in advance of the trigger, the rotating safety-lock, *R*, whose eccentric cam, when engaged with the piston, locks it

and the gun, whether the breech be open or closed.

Since the action of the mechanism depends largely on the pressure in the cylinder, *C*, the chamber-capacity of the latter is an important factor. This capacity is varied by the regulator, *D*, —a plug with a threaded stem,—closing the forward end of the cylinder, and capable of advance or retraction within the latter. A port in the cylinder, at the end of the piston's rearward stroke, gives a free exhaust to the gases.

The cartridges are held by clips, set in feed-strips of elastic brass, a strip 38 centimeters long carrying thirty rounds. The strips are arranged to hook together, forming a continuous band when required. The feed mechanism is self-contained, positive, and independent of gravity, working at any angle of elevation or depression. It withdraws the feed-strip from the packing box, brings the cartridges, one by one, by positive motion, in line with the chamber, and ejects the empty strip.

The mechanism consists of a feed-block, containing the feeding-gear and forming a guide for the feed strip; the framing or key, *T*, which fixes the feed-block to the receiver; the feed-wheel, *U*, having two toothed discs, which registers with openings formed in the feed-strips, advancing the latter and bringing each cartridge in front of the chamber, and also engages the feed-cams, f^2, cut in the piston-rod, whereby the wheel is given a step-by-step motion; and, lastly, of the sprung detent, *w*, which prevents reverse motion of the wheel by engaging a ratchet formed on the end face of the latter.

When in action, the piston, in each forward stroke, advances the breech-block, *H*, which pushes a cartridge out of the feed-strip and drives it home in the chamber, it being instantly thereafter discharged by the firing pin. Each backward stroke of the piston withdraws the breech-block with its shell-extractor, *K*, ejects the cartridge-case, and, through the cams, f^2, turns the feed-wheel one tooth, draws the feed strip forward, and brings a fresh cartridge to the loading position. The stop, *V*, before referred to, which arrests the piston at the end of its backward stroke, is pressed downward and out of action, when the latter is in position.

The breech-block, *H*, is reciprocated by the piston, the latter being formed with an upturned driving lug or tang which enters a channel in the block and with a cam, f^1, for propelling the block and for operating the locking dog, *h*, attached pivotally to the rear of the latter. Moving within the block is the firing pin which is engaged and driven home by the tang above noted. For supporting the base of the cartridge, the block is fitted with a nose-piece, *I*, which is secured by the extractor, *K*, also mounted on the block. The ejector, *L*, is journalled in the receiver.

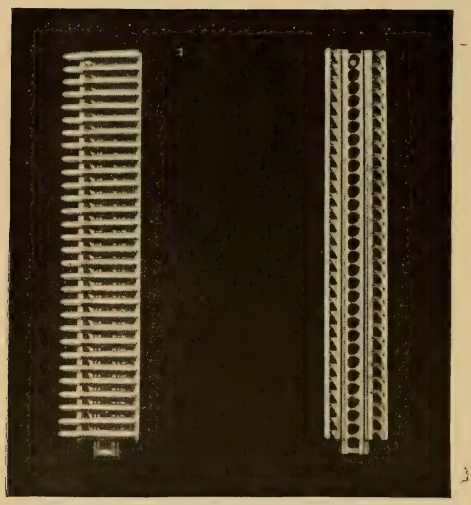
In its forward motion, the piston carries with it the breech-block, the latter resting, with the locking dog, on the unlocking, or forward, cam, while the cartridge is rammed home. As the block approaches the end of its stroke, the piston, still advancing, drives, through the tang, the firing pin against the primer, while, just previously, the locking cam, f^1, enters between the breech-block and the locking dog, bringing the latter to bear on the recoil-blocks in the receiver. After the bullet has moved forward and has passed the port, *c*, the piston returns, its locking cam disengages, its unlocking cam engages, the breech-block is withdrawn, with the extractor and shell, while the ejector, operated by the block, casts out the shell.

It will be observed that no accident from a hang-fire cartridge can occur, because the mechanism, being actuated by the gas-pressure, the breech remains closed and locked until the shot is fired. Again, the breech cannot open until the bullet has left the muzzle, because the locking dog and breech-block are operated by the piston alone, and this latter begins its backward movement only when the bullet has passed the port and admitted gas to the cylinder.

The gun may be arranged to fire any of the forms of small-arms ammunition

in service. Slow fire may be delivered at any rate up to about 100 rounds per minute, and rapid fire up to from 500 to 600 rounds per minute. The temperature of the barrel increases rapidly during fire to about 400° C., and then remains nearly constant under continuous firing. The action of the mechanism, under prolonged firing, has been unaffected by the heating of the barrel. Two men are required to work the gun, —one to load and the other to fire; but one alone can operate it in case of necessity.

The gun has thirty-one parts, excluding sights, and its weight is 33



FEED-STRIP WITH CARTRIDGES FOR A HOTCHKISS GUN

pounds. For land service the gun is generally used with a folding tripod and transported on pack animals. The weight of the gun-pack, including saddlery, pouches, covers, gun, tripod, chest, with accessories, two chests with 600 cartridges, is 213.4 pounds. The weight of the ammunition-pack, including saddlery, covers, and two chests with 1920 rounds, is 264 pounds. The weight of the naval tripod mounting is 35.2 pounds, and of the rail mount, 17.6 pounds.

THE COLT GUN.

The Colt automatic gun is a machine gun consisting of one barrel attached to a breech-casing, the latter containing the mechanism for charging, firing, and ejecting. The arm is self-operating after one shot has been fired and while the trigger is held back and ammunition is furnished. The power necessary for automatic action is derived from a portion of the powder gases, which is led through a small radial vent in the bore near the muzzle and effects the several motions after the projectile has reached its maximum velocity, and, hence, without decreasing its range and penetration. The gun,—closed, with empty chamber, with side-plate removed, and without mount,—is shown in side elevation in Fig. 17.

Embracing the barrel snugly, but not fixed to it, is the gas-cylinder, *a*, having an aperture of sufficient size to receive the discharge from the vent before referred to. Within the cylinder there reciprocates the piston, *b*, which, through lever *c* and link *d*, moves the guided slide, *e*, axially with the barrel, —the slide being thus driven rearward by the powder-gases from the vent, and both it and the piston being retracted by springs acting, through intermediate connections, on the bell-crank, *f*, of lever *c*. In its reciprocation, the slide effects the various operations required.

The ammunition is carried in belts, holding usually 250 cartridges each. The belt rests on, and is driven by, the feed-wheel, *g*, lying on its central spindle and between its two discs, each of the latter having six circumferential teeth, so placed that there is always a cartridge cradled on the top of the discs, axially with the barrel. The feed-wheel is rotated by a pawl, *h*, acting on six radial teeth on the forward face of the wheel. The pawl is actuated by the feed-lever, which, in turn, is so engaged by either of two lugs on the slide, *e*, that, in the latter's rearward motion, the pawl is caused to engage, and, in the slide's advance, to rotate the wheel through the space of one tooth. A detent is fitted to prevent backward movement of the wheel.

The extraction of the cartridge from the belt is performed by the cartridge extractor, *j*. This extractor is a lever,

hooked at the forward end for engaging the cartridge and pivoted at the other end to a slide. On the same pivot, *k*, are borne the two cartridge guides, which are spring tempered and form a horizontal clamp, held open, when the slide is advanced, by the inclined sides of the belt-guide, *m*. When the slide moves rearward, the extractor and guides move with it, engage and grip the cartridge, withdraw it from the belt, and deposit it in the carrier, *n*. The latter is a lever, channeled on its upper side, pivoted at *o* to the breech-casing, and carrying a pivotally sprung dog, *p*, on its rear arm. In its backward stroke, the slide rides over the dog, which yields, without material movement of the carrier. In advancing, a lug on the slide strikes the rear face of the dog, depressing the rear arm of the carrier, raising its forward end, and presenting a cartridge in front of the breech-bolt, *r*, ready to be loaded into the chamber. The slide-lug, in its further advancement, depresses the forward end of the carrier into position for the succeeding cartridge.

The breech-bolt, *r*, is cylindrical, with a central and partial guide-rib depending into a groove in the slide and secured therein by a pin, *s*, which passes through a cam-slot in the rib, the slot being so curved as to permit a limited motion, both vertically and horizontally, of the bolt. When the slide is in the advanced position, the bolt is closed, with its rear end depressed and lying against the recoil-shoulders of the breech-casing. As the slide retreats, the bolt, owing to the contour of the slot, first rises, clearing the shoulders, and then moves to the rear with the slide, leaving space for a fresh cartridge. When the slide advances, the bolt moves forward, rams the cartridge home, and then cants into the locking position.

In a slot on the right side of the bolt is borne the shell-extractor, *x*, which grasps the head of the cartridge as it is forced up by the carrier; the extractor has a slight rotary motion about a vertical pin, a small spiral spring under its rear end, holding the nib of the ex-

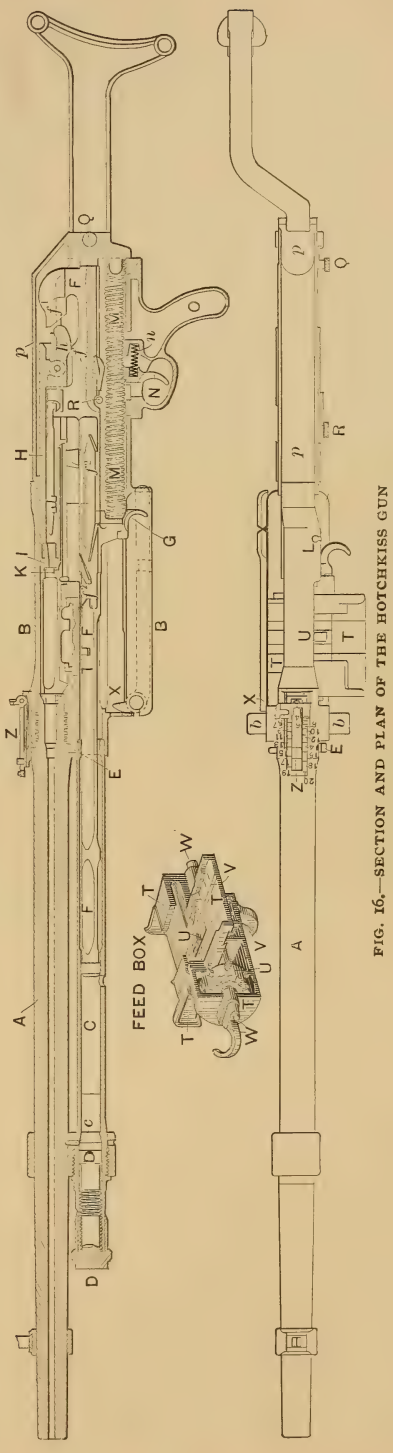


FIG. 16.—SECTION AND PLAN OF THE HOTCHKISS GUN

tractor in the cannelure of the cartridge. The ejector (not shown) is contained in a groove on the left side of the breech-casing. When the head of the shell is clear of the chamber, it strikes a lug on the inner side of the ejector, the blow releasing the shell from the extractor and throwing it outward through an opening in the right side of the breech-casing.

The breech-bolt is drilled axially for the firing pin, *t*, whose end projects from the rear of the bolt. The pin is retracted by a spiral spring recessed in the bolt and is driven forward against the primer by the blow of the spring-pressed hammer, *v*. The forward movement of the latter is controlled by a spring-pressed trigger, *w*, and a spring-pressed sear, or automatic trigger, *y*, the latter acting to hold the hammer until the instant of firing, when the gun is self-operative.

In single-shot firing, the trigger is released manually and permitted to engage at once; in automatic firing, the trigger is held back continuously, leaving the sear only in control of the hammer. Both trigger and sear engage a groove formed around the hammer-head, when, in the rearward stroke of slide and breech-bolt, the hammer is forced back and its spring compressed.

The automatic release of the sear is effected by an oscillating trip-lever (not shown), which is pivoted, at its mid-length, to the left side of the breech-casing. In its forward end the trip carries a pin which bears on the top of the slide; the rear end of the trip is in position to engage the sear. When the slide is in the advanced position, the trip-pin is elevated, the rear of the trip is depressed, and the toe of the sear is thereby forced out of engagement with the hammer. As the slide moves rearward, a depression on its upper surface is brought under the trip-pin, thus permitting the sear to engage the hammer, until, in the slide's advance, the sear is again disengaged.

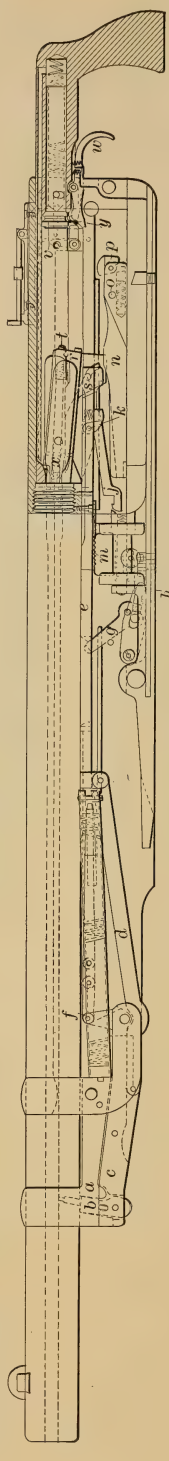


FIG. 17.—SECTION AND ELEVATION OF A COLT GUN

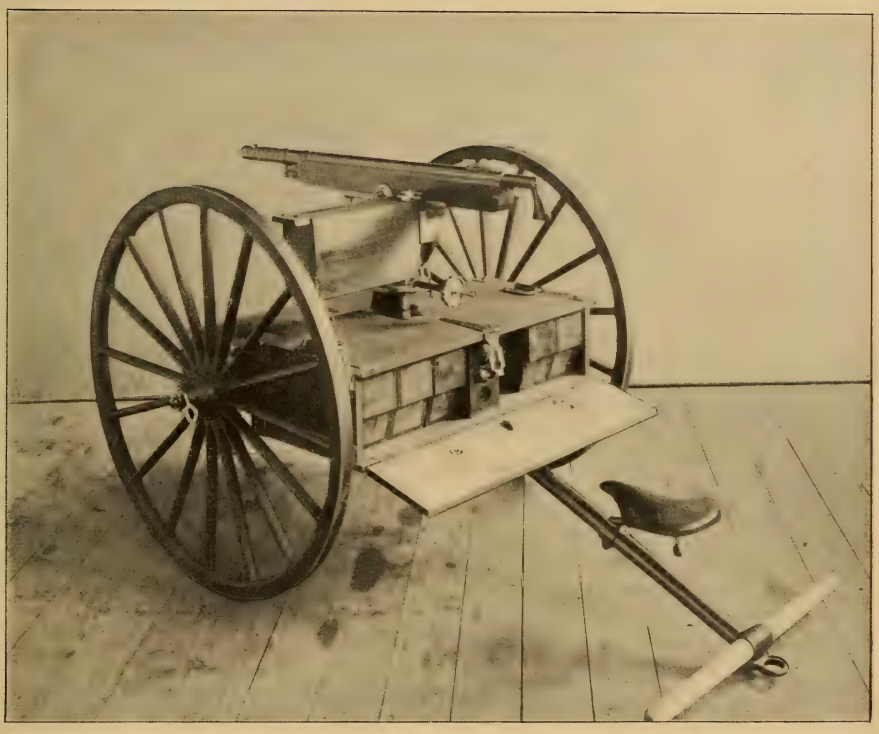
On the right side of the breech-casing there is fitted a thumb-piece controlling a lever safety-latch inside, which lever may be so set as to rise in front of the hammer, thus restraining it, although both trigger and sear be released. The rapid strokes of the hammer in its casing are utilised in forcing a jet of air, through a channel in the upper part of the handle, into the chamber of the gun, for cooling and clearing the latter of unburnt powder.

To begin firing, the feed-belt is entered and the gas-lever is thrown down once by hand; the lever is then released and the trigger pulled for single-shot firing, or held back for continuous automatic firing. In recent tests to determine the gun's durability, rapidity, and non-liability to fouling, 8000 rounds were fired without fault. At 200 yards, for accuracy, 100 consecutive hits were scored in 16 seconds. Of 140 shots, fired rapidly at a 300-yard target, all but two sighting shots fell within a circle of 12-inch radius.

The barrel is made much heavier than that of the corresponding small arm, to reduce vibration and retard heating. Its life is nearly 10,000 rounds, using the new United States naval standard bullet, 112 grains in weight, and having a jacket of tinned copper. No

limit to the endurance of the mechanism has been reached, although upward of 20,000 rounds have been fired from one gun, the only defect being a firing pin scored by gas from pierced primers.

The following particulars refer to the Colt automatic gun, United States naval type, calibre, 6 millimetres:—



A COLT GUN. U. S. ARMY MODEL

Rate of fire, about, per minute,	400
Diameter of bore, land to land,	6 mm.
Rifling, form,	Metford.
Twist, one turn in	7.5 ins.
Grooves, number,	6
" depth,	0.004 ins.
Diameter of gas vent,	0.9 in.
" " barrel,	1.56 in.
Weight of gun	40 lbs.
" " tripod mount, complete,	53 lbs. 4 oz.
Loaded belt, 250 rounds,	12 lbs. 2 oz.
Feed box,	2 lbs. 1 oz.

The Colt automatic gun is made in different calibres, as follows:—6 mm., 7 mm., 30 cal., 7.65 mm., and 8 mm. The effective range of these calibres is 2000 yards. The penetration, in pine, is from 48 to 60 inches, according to calibre. The velocity varies, with cartridge used, from 1960 to 2500 feet per second. The rapidity of fire is regulated, as desired, in the construction, and ranges from 400 to 500 shots per minute. Smokeless powder and nickel-jacketed bullets are used exclusively in this arm. The gun, including sights, has 94 parts. The weight of the field or landing carriage, complete,—with gun, mount, ammunition-chests, cartridge-belts, and feed-boxes for 2000 cartridges,—is 230 pounds. The United States Navy uses this gun, with both the tripod-mount and field-carriage. The Colt automatic arm was used most effectively in the late war between the United States and Spain in the defence of the camp of the United States marines at Guantanamo Bay, on which frequent attacks, in overwhelming force, were made by Spanish troops.

THE BEST WATER-TUBE BOILER FOR THE NAVY

A War Lesson

By Passed Assistant Engineer J. K. Robison, U. S. N.

THE various requirements which the late war between the United States and Spain showed to be necessities of a very practical kind, were detailed recently in a paper presented by the author to the American Society of Naval Engineers. In this the fact was set down, to begin with, that the need of the water-tube boiler for warships had been demonstrated beyond all question, and following this were given the several conditions which a boiler of this type should fulfill in order to be entirely satisfactory.

This portion of the paper is reprinted in the following pages, and presents in a nutshell probably all the important points about the water-tube boiler question.—The Editor.

The boilers must have a large grate surface so that steam can be furnished with readiness to the engines. To go further, contract-trial speeds should be obtained by burning not much more than 25 pounds per square foot of grate surface under the boilers. This would insure the ability to attain this speed, a maximum speed in practice, without great difficulty. The boilers should be divided into small units so that it will be possible to overhaul them, one by one, without at any time making any great inroad into the steam-producing plant.

We want to avoid the great fatigue to the men, the great loss of feed-water, the rapid fouling of the boilers incident to their being maintained at all times with lighted fires under them all. We want to avoid any great expenditure of coal incident to keeping the vessel at all times in complete readiness for action. The boilers must be accessible to repairs and cleaning, inside and out.

To fulfill these requirements we must have boilers that are capable of generating steam quickly from a cold boiler. Such boilers could be maintained with heavily primed fires ready for lighting, but not lighted until required, and such boilers would be capable of furnishing a full supply of steam to the engines at short notice. By the use of hydrokineters, the water in these boilers could always be kept hot.

The wear and tear on the ships would be decreased and could be controlled. The ship being fitted with such boilers, a full watch would not be required at all times in the terrific heat of the fire-rooms; having the men within call would be sufficient. The crew would not be worn out with hard work to such a deplorable extent as now obtains.

As the time required to raise steam from a cold boiler is largely due to the time required to heat to the boiling point the water contained in the boiler, in order to have boilers that will be capable of raising steam quickly, we must have boilers having a small amount of contained water as compared with the cylindrical boilers that are now in use.

The foregoing means that water-tube boilers are tactical necessities, as this type of boiler is the only one that is capable of being divided into small units, and containing a small amount of water. The arguments for and against water-tube boilers have been gone over again and again until they are threadbare; but the fact that we must have

boilers that are capable of being divided into small units, and that are capable of quickly generating steam from a cold boiler, must settle the question. Whatever the faults and virtues of this general type of boiler, it must be used to satisfy the manifest requirements of the service. War conditions that we have found to exist, and that will again exist, require the use of water-tube boilers.

We find that water-tube boilers must be used on men-of-war, but we also find a great deal concerning the type of water-tube boiler that must be used. It may or may not be capable of sustaining a high-forced draught. It is not a great advantage that it should be so capable, as in the course of its ordinary use in time of war no very great advantage could accrue from this ability. They could be depended upon to burn only 25 pounds of coal per square foot of grate surface, this figure rising, perhaps, in emergencies, for a short time to 30 or even 35 pounds. Such rates of combustion are, however, obtained with very moderate forced draught. It is fortunate that this quality must not be insisted upon. The comparatively direct and unobstructed course of the gases of combustion in most types of water-tube boilers renders them uneconomical with high forced draught.

An increase in the space on board ship devoted to machinery, above the large amount already so allotted, must be avoided. Inasmuch as the grate surface of the new boilers must be greater for the same power developed at the engines, than that in the type of boilers now used, there would naturally be an increase in the boiler-room space required. This must be avoided; and this can be done only by increasing the ratio of grate surface to floor space occupied above that in cylindrical boilers. This ratio must be a large one, and the larger the better.

Considering the crew a ship is sure to have in time of war, and the fact that frequently the water tenders will be new to the ship, and, possibly, even to the type of boiler used, the boilers must not be complex. The number of attachments must be as small as possible to minimise the work of these busy men.

No great efficiency in firing must be required to attain a good efficiency of the boiler. This follows from the fact that the firemen in the navy in time of war are not equal to doing any particularly good firing.

The fact that no great efficiency in firing must be expected or required, means that the complete combustion of the fuel must not be attempted in one chamber above the fire. There are sure to be holes in this fire. It will not be the same thickness in one place as in another, and the coal will not lie evenly over the grate. At some point, then, beyond which an opportunity for the economical extraction of the heat from the furnace gases is afforded, the gases of combustion must be thoroughly mixed and a combustion chamber furnished.

The care of the boiler while steaming must not be attended with any great difficulty. The water level must be steady. This requires a large area of cross section of the boiler at the water level, and in general requires a large amount of contained water in the boiler. This amount of water must not, however, be so great as to interfere with the ability of the boiler to furnish steam quickly from a cold condition.

The parts of the boiler must be afforded a free expansion to make the quick raising of heavy fires under a cold boiler possible without any danger of causing leaks. For the same reason, a good, free circulation of the water in the boiler must be assured. As it is not possible to entirely keep salt water out of the boilers, they must be capable of use with salt water, and the interior must be accessible for cleaning. It must be possible to remove salt and other scale from the water side of the heating surfaces. The tubes must, therefore, be straight tubes and not of very small diameter. Any attempt to disprove the foregoing by statements that in certain types of boilers there will be no scale deposited upon the heating surfaces that are the most exposed to

the heat of the fire must be viewed with doubt. The facility of repairs of the straight-tubed boilers over those that are supplied with bent or curved tubes would also call for the use of straight tubes.

The above conclusions are direct deductions from actual war experience. They must be satisfied to satisfy real war conditions.

If the reasoning has been correct from effect to cause, these are requirements that it is absolutely essential to have fulfilled to secure a proper efficiency of our warships. They form only a part of the requirements of good water-tube boilers, but an attempt has been made only to point out certain particulars of design that are required for efficiency, as determined by the experience of this war. There are many other lessons to be drawn from the late war between the United States and Spain, but the necessity for the use of water-tube boilers is the great lesson to the engineer. To know that certain qualities of this type of boiler must be obtained to insure satisfaction, is also interesting. To have a successful and satisfactory water-tube boiler, we must have a boiler that is simple, economical under the ordinary conditions of use, and with as few joints as possible. It must be accessible for repairs and cleaning. It must have large grates, not long grates, but grates that are short so as to be easily worked, and that gain area by an increase in the total width.

There have been experiments with water-tube boilers for years. There is an infinite variety of this general type of boiler. They have tubes of all shapes and sizes, placed at all angles. These tubes are connected with many types of steam and water drums, placed some within and some without the boiler proper. These boilers are supplied with feed heaters, air heaters, and all sorts of economisers. But the boiler that we want, the boiler that we must have, has certain fixed requirements of design. Many of the types of water-tube boilers fail at once to satisfy those requirements. Is there one that will satisfy them all? If there is such a boiler, which one is it? If no such boiler yet exists, what modifications must be made in that type of water-tube boiler that comes nearest to satisfying the requirements to make it satisfactory now and hereafter? For the sake of uniform design, some one type must be found and adhered to.

SHOP TESTING OF LOCOMOTIVES IN THE UNITED STATES

By Richard A. Smart, M. E.

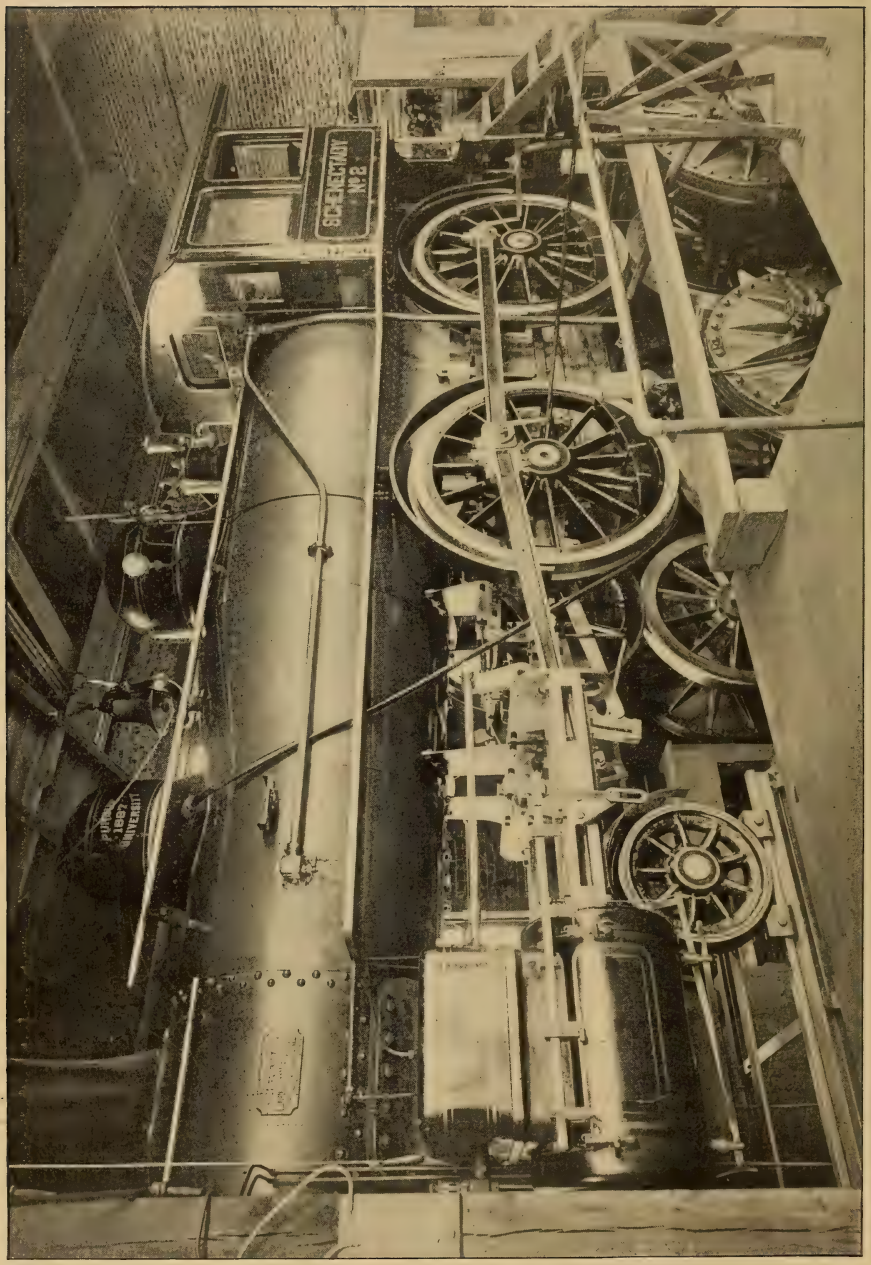
IT is a well-known fact that one of the most potent of the agencies which are developing the resources and promoting the general welfare of all countries is the railway. Evidence is not wanting on every hand to prove the truth of this assertion, if, indeed, so evident a statement needs corroboration. But, however well this may be understood, few of those not directly connected with the railroad appreciate the important contribution which the several elements in the railway's material structure,—as, for instance, the locomotive, the permanent way, the block signal, and the air brake,—make to the efficiency of the whole. The locomotive is one of the most important of these elements, and so largely is it concerned in the problems of railroad operation that any substantial improvement in its construction or performance results in an immediate advance in the service, which is felt not only by the traveller, but by every one to whose welfare the railroad in any degree contributes.

Not only does the important part which the locomotive plays in the world's progress entitle it to distinction from an economic point of view, but from the standpoint of the engineer it occupies a unique position. There is, perhaps, no machine whose construction and operation are bounded by such narrow limitations as are those of the locomotive. Confined to certain definite dimensions of width and height, and, practically, of length; to a limiting weight which, it seems, must nearly have been reached; to a minimum of cost and a maximum of simplicity in construction, it is required to serve under conditions more severe than those to which, with few exceptions, any other machine is subject.

It is, therefore, somewhat remarkable that there has been, until within the last few years, very little well-established information in regard to locomotive performance and economy. Practice in different places and with different designers has varied in regard to the design and dimensions of many of the more important parts. Within the last decade, as the demands for increased power and speed have become more urgent, and, too, as the possibilities for improvement have become less, designers have felt the need of more accurate knowledge on the subject, and, as a result, the attention of railway motive power men has been turned to the best methods of securing the desired information by experiment.

The facility with which the stationary engine has lent itself to the conduct of experimental investigation of its performance has had much to do with its present high efficiency. The conditions of its operation are, in general, especially favourable to the securing of accurate data regarding its economy. The accessibility of the various parts while in service and the constancy of the conditions of operation make it possible and easy to secure reliable results.

With the locomotive, almost the reverse is true. The conditions of operation are widely variable, and the peculiar service required renders the application of measuring and recording instruments and the taking of observations difficult in the extreme. The load is constantly changing, due to changes



THE TESTING PLANT AT PURDUE UNIVERSITY

in grade and curvature, and frequent stops and slow downs are usually unavoidable. Furthermore, it is difficult to duplicate conditions on different days; differences of temperature and of the velocity and direction of the wind which may occur during succeeding tests introduce variables, and, consequently, errors of considerable magnitude. For these reasons the accurate determination of the economy of the locomotive while in service is almost impossible.

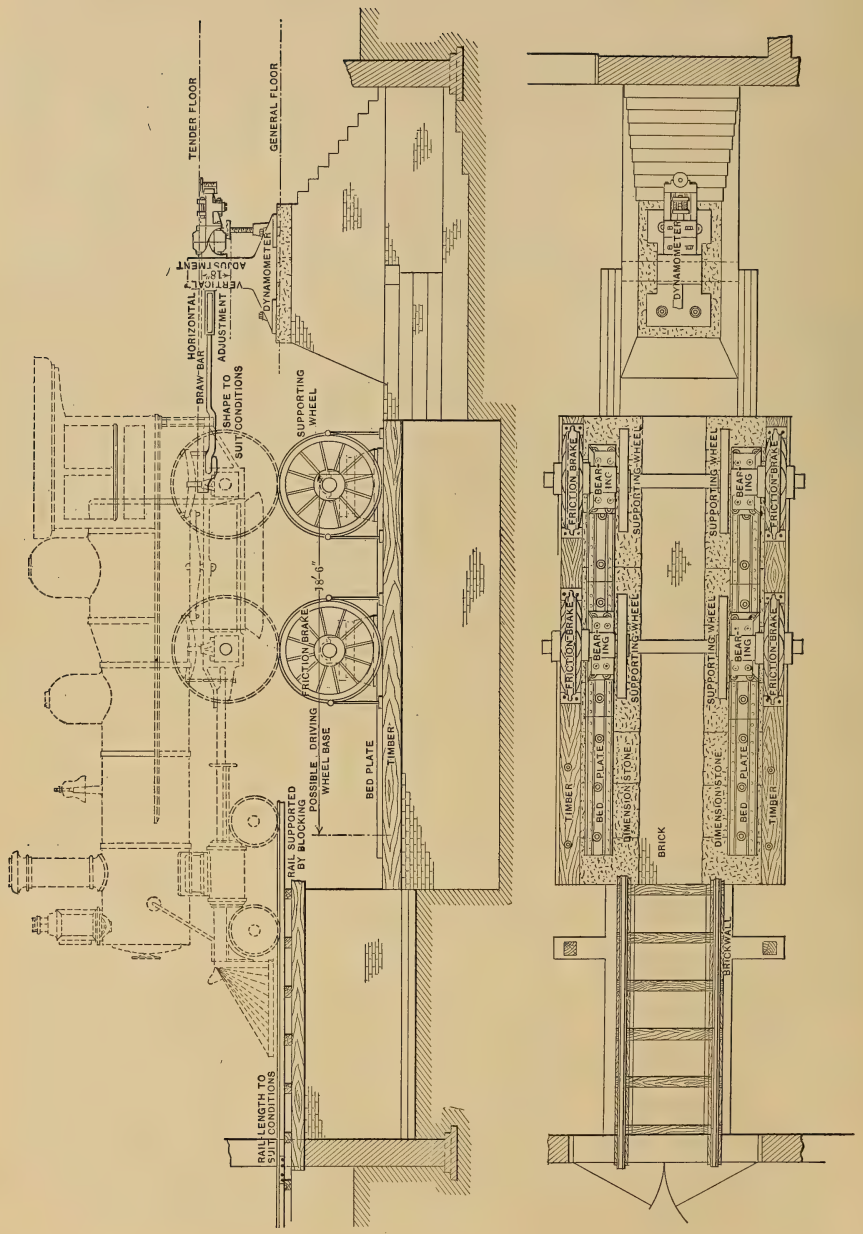
Notwithstanding the difficulties just cited in the way of locomotive testing on the road, a great many such tests have been made from time to time. The larger roads have conducted special investigations of many kinds, both with their own engineering force and through the co-operation of the various engineering schools. Some of these tests have had for their object the determining of fuel economy under different conditions, while others have dealt solely with questions of tractive effort, steaming capacity, and matters not involving the measurement of coal and water. Many roads have built, at considerable expense, dynamometer cars to measure and record the draw-bar pull required to draw trains of various weights and at various speeds. These tests have yielded a great deal of valuable information concerning locomotive performance which has had its effect upon the design and the methods of operation. The field for improvement was large, and the sources of loss and waste were many and of such magnitude as to be readily revealed by road tests.

But, as improvements have been made, the chances for further betterment in economy have diminished, and correspondingly greater refinement is needed in the methods of testing the value of those changes. While there are many facts which can be revealed only by tests in road service, notably those connected with strength and wearing and riding qualities, it is now very generally recognised by those conversant with the subject that for investigations involving the accurate determination of coal and water consumption, recourse must be had to the method of testing known as shop testing.

The term shop testing has been applied to all methods of testing in which the moving parts of the locomotive are allowed motion while the machine, as a whole, is stationary. If, while fulfilling this requirement, conditions of operation similar to those in regular service, —the same load, speed and boiler pressure,—can be secured and maintained at will, it is apparent that we have found a means of conducting experiments which possesses great advantages, both in convenience and accuracy, over the road test. Every part of the machine is at all times accessible to the experimenter for inspection,—a feature of special importance when testing the performance of new devices. In fact, a full understanding of the stresses and strains occurring in the various parts could hardly be had without the opportunity afforded by the testing plant to study carefully the moving machine.

The first installation worthy the name of a locomotive testing plant in the United States was, curiously enough, not the production of those directly connected with railroading, but the outgrowth of the activity and forethought of a technical school. In the fall of 1890 the authorities of Purdue University decided to erect a plant on which a locomotive could be tested under conditions approximating those of ordinary service and with the ease and facility accompanying the testing of stationary engines.

In May, 1891, a locomotive was ordered from the Schenectady Locomotive Works. It was at that time practically their standard 8-wheel locomotive, with 17 × 24-inch cylinders and 63-inch drivers. Its weight was 85,000 pounds, of which 56,000 pounds were on the drivers. A testing plant was designed by Professor W. F. M. Goss, which consists in its elements of a locomotive mounted on supporting wheels in such a way that it can be run under its own steam at speeds equal to those obtained in actual service and under loads commensurate with its capacity. The load is supplied by four hydraulic friction



ELEVATION AND PLAN OF THE PURDUE LOCOMOTIVE TESTING PLANT

brakes of the Alden type, which are keyed on the shafts of the supporting wheels and interpose a resistance to their motion. Work is thus furnished for the locomotive, not in putting a section of track behind it, but in moving the top of the supporting wheels backward, a condition similar in its effect to the load supplied by a train on the road. The maximum capacity of the four brakes is about 800 horse-power. A view of the supporting mechanism and friction brakes is shown on this page. The brake in the foreground is shown removed from its place on the rear supporting shaft, it being sometimes necessary, in light power tests, to slip off one or two brakes on account of their rather large minimum load.

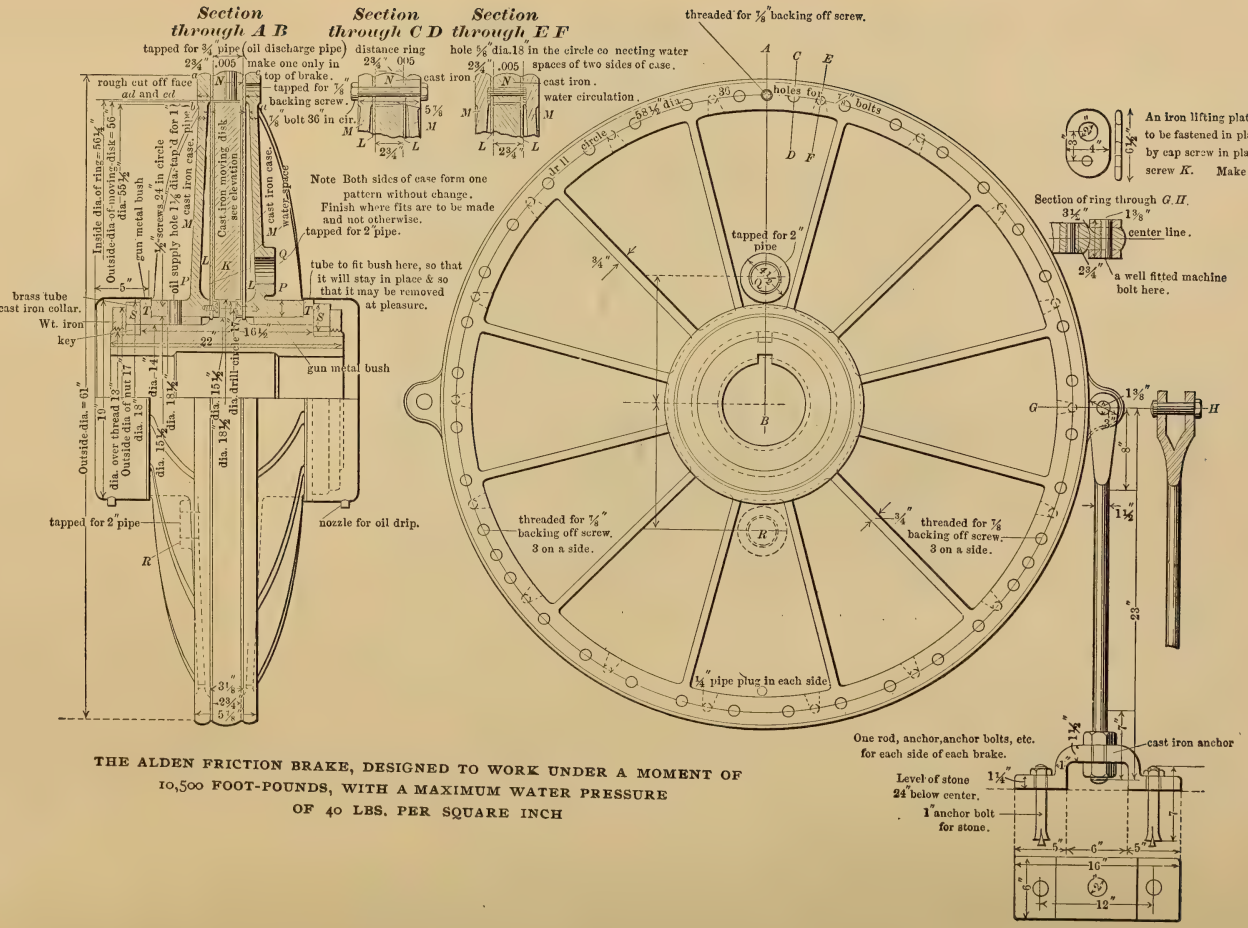
The first effect of the retarding action of the brakes to the motion of the supporting wheels is the tendency of the locomotives to move forward with a force proportional to the retarding action. This forward tendency is opposed by the draw-bar, which alone holds the locomotive on the supporting wheels. The draw-bar is attached to a dynamometer of 30,000 pounds capacity, which serves to measure the pull. Thus the load, and, consequently, the speed, are very readily controlled by varying the amount of water flowing through the brakes.

The locomotive is fired with coal in the usual way, and is operated from the cab in a manner similar to that employed on the road. The stack projects through a depression in the roof of the building, thus easily disposing of the smoke.

The plant as originally built was destroyed by fire early in 1894. It was immediately rebuilt in a new location, with many added improvements. A wheel foundation is provided, nearly twenty-five feet in length. This is sufficient to include the wheel base of the majority of six and eight-coupled machines. The foundation plates are so arranged that the distance between the centres of the supporting wheels can easily be adjusted. For six-coupled engines a third pair of wheels may be added.

Directly on the stone foundation are cast-iron bed-plates extending nearly the length of the foundation, and on these are the pedestals carrying the journal boxes of the supporting shafts. The lower flanges of the pedestals are slotted, and the bed-plates have threaded holes spaced at equal distances along their length. By these means the pedestals may be adjusted to any position along the length of the foundation. The journal boxes have plain babbitted bearings. Between each journal box and its pedestal is interposed a cushion of wood to absorb the vibrations which are set up when the machine is moving at a high speed of rotation. The outer edges of the wheel foundation are capped with timbers, to which the brake cases are anchored. The load on the brakes is controlled by means of water pressure, the water serving the double purpose of furnishing the

THE SUPPORTING WHEELS AND BRAKES


Section through A B
Section through C D
Section through E F
tapped for ¾" pipe
oil discharge pipe) make one only in top of brake.
distance ring
hole ⅝" dia. 18 in the circle connecting water spaces of two sides of case.
cast iron.
water circulation.
tapped for ⅞" backing screw.
⅞" bolt 36 in cir.
rough cut off face ad and ad
Inside dia. of ring = 56¼"
Outside dia. of moving disk = 56"
dia. 58½"
gun metal bush
screws 24 in circle
oil supply hole 1⅛" dia. tapped for 1"
Cast iron moving disk. see elevation
cast iron case.
water space
Note Both sides of case form one pattern without change. Finish where fits are to be made and not otherwise.
tapped for 2" pipe.
tube to fit bush here, so that it will stay in place & so that it may be removed at pleasure.
brass tube
cast iron collar.
Wt. iron key
gun metal bush
Outside dia. = 61"
dia. over thread 13"
Outside dia of nut 17"
dia. 13"
dia. 14"
dia. 15½"
dia. 13½"
dia. drill-cuts
tapped for 2" pipe
nozzle for oil drip.
R
threaded for ⅞" backing off screw.
holes for ⅞" bolts
58½" dia.
30
circle
tapped for 2" pipe
¾"
threaded for ⅞" backing off screw. 3 on a side.
threaded for ⅞" backing off screw. 3 on a side.
¼" pipe plug in each side
An iron lifting plate for side of case to be fastened in place when needed by cap screw in place of backing off screw K. Make one only.
Section of ring through G H.
3½"
1⅜" center line.
2¾" a well fitted machine bolt here.
1⅜"
G
H
23"
1½"
One rod, anchor, anchor bolts, etc. for each side of each brake.
cast iron anchor
Level of stone 24" below center.
1¼"
1" anchor bolt for stone.
16"
12"

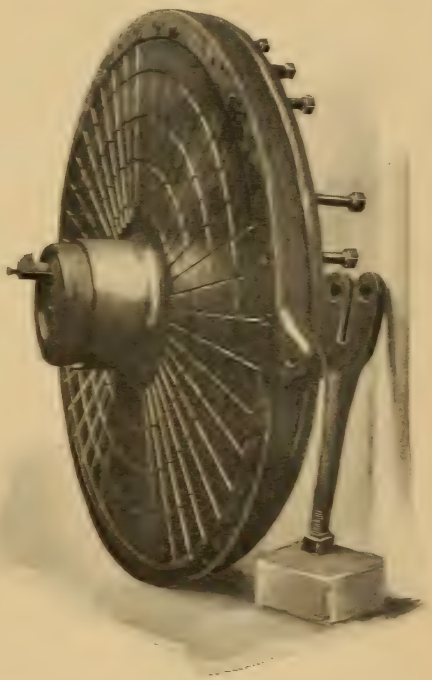
THE ALDEN FRICTION BRAKE, DESIGNED TO WORK UNDER A MOMENT OF 10,500 FOOT-POUNDS, WITH A MAXIMUM WATER PRESSURE OF 40 LBS. PER SQUARE INCH

braking pressure and of carrying off the heat developed.

The construction of the brake will be understood from the annexed cuts. A cast-iron disk, 56 inches in diameter and 2¾ inches thick, is keyed to the shaft of the supporting wheel, and, hence, moves with it. On either side of this disk are copper plates 5-32 inch thick, which form a part of the inclosing case The cast-iron sides of the case have a bearing upon the hub of the disk, the rubbing surfaces being fitted with gun metal bushings. The sides of the case are connected by a central ring to which they are secured by through bolts. The copper plates referred to are secured at their outer edges by being clamped between the sides of the case and the annular ring already mentioned. The circulating water enters through the side casing on one side, fills the annular space between the case and the copper disk on that side, passes through openings provided for the purpose in the central ring into the corresponding annular space on the other side, and, thence, is conducted away by suitable piping. The rubbing surfaces receive lubrication by means of the continuous flow of oil which passes from a storage-can to the hubs of the wheel, from which point it is thrown out to the periphery of the disk by spiral and radial grooves cut in the surface of the latter. From the periphery of the disk the oil is taken off through a pipe which returns it to the hubs. This continual circulation is kept up whenever the disk is in motion. The oil finally escapes by slowly dripping out around the hubs, where it is collected for further use.

These brakes absorb, but do not measure, the work done by the locomotive. This quantity is determined from the draw-bar pull. The dynamometer for measuring this consists of the weighing head of the Emery testing machine,—a machine too well known to need description. It is provided with a set of helical springs whose function is to apply an initial stress to the draw-bar in the direction which the locomotive is to run. This initial stress serves to put the parts of the dynamometer and scale under tension and thus to give a steady indication to the pointer of the scale.

A "stationary tender" is provided at a sufficient height above the rail level to serve as a platform from which to fire. A pair of platform scales is set flush with the floor at the head of a runway which extends to the rear into a

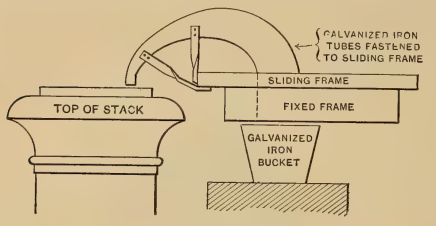


ANOTHER VIEW OF AN ALDEN BRAKE

coal room. The injectors draw their supply from a feed-water tank provided with calibrated measuring barrels and a glass water gauge. The conditions under which the engine is operated are at all times under the control of a single person, whose place is just at the right of the steps leading to the tender floor. From this position he can see the throttle and reverse lever and observe all that goes on in the cab. At his right is the dynamometer scale case, in front are the gauges giving the water pressure on the brakes, within easy view is a speed recorder, showing the speed of the engine in miles per hour, and under his hands are the valves controlling the cir-

culation of water through the brakes.

This plant has been in service seven years, and has proven its adaptability to the peculiar requirements and its ability to withstand the severest conditions of operation which the locomotive



THE CINDER TRAP

is capable of maintaining. In 1897 the first locomotive was sold to the Schenectady Locomotive Works and a new machine was purchased in its stead. This engine is larger and heavier than the first, and, among other improvements, is provided with a boiler built for a working pressure of 250 pounds, in order to investigate the value of high steam pressure in locomotive service. It is also arranged to be readily convertible into a compound locomotive.

Purdue plant. Supporting wheels are provided for the drivers, and their axles carry Prony brakes of special design at each end.

The foundation upon which the pedestal boxes of the supporting shafts rest is composed of cross-ties laid on a gravel bed, and carrying 16″ × 16″ longitudinal timbers, upon which are cast-iron bed-plates.

The form of brake used consists of a cast iron wheel with chilled tire, 33 inches in diameter. Around this wheel is a steel band, fitted with cast iron rubbing blocks. The band is attached to a lever above the wheel, and power for tightening the band is applied by the use of compressed air in a 6-inch air cylinder. The wheel is surrounded by a sheet iron casing, through which cooling water is circulated. The air pressure can be easily adjusted to give any desired speed, and is regulated by an ordinary throttling governor, belted to one of the lower axles. By this means it is possible to regulate the speed very closely. No dynamometer is provided, but the pull of the engine is taken by a

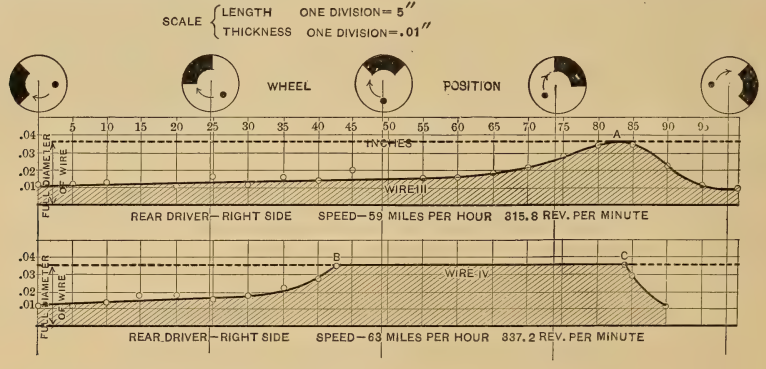

SCALE LENGTH ONE DIVISION = 5″
THICKNESS ONE DIVISION = .01″
WHEEL POSITION
INCHES
FULL DIAMETER OF WIRE
WIRE III
REAR DRIVER—RIGHT SIDE SPEED—59 MILES PER HOUR 315.8 REV. PER MINUTE
WIRE IV
REAR DRIVER—RIGHT SIDE SPEED—63 MILES PER HOUR 337.2 REV. PER MINUTE

DIAGRAM OF THICKNESS OF WIRE AFTER PASSING UNDER LOCOMOTIVE DRIVER

Stimulated by the success attending the operation of the Purdue plant, the Chicago and Northwestern Railway, in 1895, erected a locomotive testing plant at their Chicago shops. This plant was designed by Mr. Robert Quayle, Superintendent of Motive Power and Machinery, and Mr. E. M. Herr, then Assistant Superintendent of Motive Power and Machinery, and conforms closely in its general arrangement to the

strongly-built buffer. Ample provision is made for supplying and weighing the coal and water used.

The process of conducting an efficiency test on the Purdue plant usually involves a run of about 100 miles. The duration of the tests, therefore, varies inversely as the speed of rotation. Since the greatest errors occurring during the conduct of these tests are those arising in making determina-

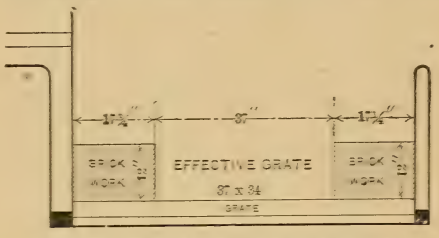
tions of the coal and water at the beginning and end of the test, the amount of these errors is a function of the total weight of coal burned and water used, and not of the time of the test. A run of 100 miles with the range of loads employed is found to use a sufficiently large total weight of fuel and water to reduce the errors of starting and stopping to a practically negligible amount. As ordinarily conducted, seven observers are employed for a test, and the operating force numbers five. The method of conducting a test is, briefly, as follows:—

The engine, having been under steam for several hours, and having been run for an hour or so to thoroughly warm all parts, is started up and brought rapidly to the conditions of boiler pressure, speed, load and cut-off under which the test is to be run. The fireman, whose experience with the plant has made him expert in his duties, has a light, clean fire in the box. Since the engine is under way but a few minutes before the beginning of the test the depth and condition of the fire can be accurately gauged. The test is then begun on a signal from the time keeper, the various observations are taken, and the fireman begins to fire from weighed coal. Cards are taken at regular intervals from indicators fitted with short connections to the cylinders and steam chest. The smoke-box draught is read from *U*-tube gauges, and is registered on a recording gauge. Steam pressure is read from a gauge on the steam dome. It is also registered on a recording gauge.

A throttling calorimeter provides means for determining the moisture in the steam. Coal is brought up in barrow loads as needed, weighed on the platform scales and dumped within convenient reach of the fireman. Water is weighed out in the feed tank to supply that drawn by the injectors, which are kept in continuous operation during the test. The temperature of the smoke-box is taken by two methods, the first employing a Le Chatelier pyrometer, and the second making use of a special copper-ball calorimeter. The speed is taken from a revolution counter, and a continuous record is kept by a Boyer speed recorder. Various other observations are taken in order to secure complete data for working up the test. All the conditions are kept constant during the run.

Great care is taken during a test to keep the fire light and clean, and particularly is this true just before the close of the test. Immediately upon shutting down the engine at the close of the trial, the fire is dumped and quenched. It has been found that with skillful firing the quantity of coal and ash on the grate at the close is within a few pounds of that at the start, and this fact is borne out by the records of the weight of coal picked out of the ash, which is a remarkably constant quantity.

During a test, samples of coal and



METHOD OF BLOCKING OFF THE GRATE

smoke-box gases are taken for analysis, and after the test similar samples are secured of the ash and cinders. The amount of cinders thrown out of the stack is determined by a trap of special form (shown opposite) which projects over the stack and catches the cinders passing out of a certain portion of the cross-section of the stack. The nozzle is moved into several different positions and left in each a sufficient length of time to make an accurate determination of the weight of sparks caught. The area of the stack is then integrated to find the weight of the whole number of sparks.

During the test, if it be a heavy one, about 4000 pounds of coal are burned and about 32,000 pounds of water evaporated. This latter quantity implies, occasionally, a rate of 400 pounds of water per minute, which would require the generation of about 470,000 B. T. U. per minute to convert it into steam

at 180 pounds pressure. About one hundred and eighty indicator cards are taken.

In view of the important place occupied by the locomotive in the generation of power, it is a matter of some surprise that testing plants adapted to the locomotive should be of such late origin, and that more of them have not already been built. The usefulness of such a plant in the solution of vexed questions pertaining to locomotive design and performance cannot better be illustrated than by reference to some of the more important investigations conducted upon the Purdue plant.

Since the plant was erected 150 complete efficiency tests have been run, besides 250 tests conducted for special purposes, the whole corresponding to a total run of about 30,000 miles. Fifteen thousand indicator cards have been taken and worked up.

One of the most striking experiments was that made to demonstrate the "hammer-blow" effect of the counterbalance at high speeds. A soft annealed iron wire, slightly greater in length than the circumference of the driver, was fed between the driver and supporting wheel, while the engine was running at high speed. The normal weight supported by the driver would be sufficient to flatten out the wire into a thin ribbon. It was found, however, that the wire came out with some portions thicker than others, and when speeds of 60 miles and over were reached, portions of the wire came out untouched. These portions were those passing under that part of the circumference of the drivers nearly opposite to the counterbalance, and they evidenced the fact that the upward tendency of the counterbalance was sufficient to lift the driver clear of the rail at certain portions of its revolution. The lower diagram on page 82 shows the thickness of one of these wires plotted to an enlarged scale.

In assisting the 1896 Committee on Exhaust Nozzles of the American Railway Master Mechanics' Association with the conduct of their investigations, some elaborate experiments were made on the form of the exhaust jet. This work was the means of disclosing the fact that the action of the jet upon the gases in the smoke-box is an inducing and entraining action, and not, as had been generally supposed, a plunger or pump-like action.

A notable series of tests was made in 1896 to determine the loss of evaporative efficiency with increasing rates of combustion. This was accomplished by blocking off successive portions of the grate surface (see page 83) and burning in each test the same weight of coal per hour as in the first test, which was made with full grate area. Since there was but little variation in the heat to be transmitted by the heating surface, and, consequently, in its efficiency, any change in evaporative efficiency was chargeable to the imperfect combustion and cinder losses due to high rates of combustion.

The plant has, from time to time, lent itself to many investigations in addition to those conducted upon it as a part of the year's regular work. It has participated in the work of the committees of the Master Mechanics' Association on slide valves and on high steam pressures, and has been used for the investigation of many problems and the testing of numerous devices at the instance of railway and private companies. Not less active has been the Chicago and Northwestern installation. Many important investigations have been conducted upon it, and much useful information has resulted to the railroad company and to the railroad world.

The locomotive testing plant has thus proven not only its practicability, but its usefulness. As might have been expected, many unusual problems were met with, both in the design and in the method of operation. The problem of absorbing, continuously, from eight hundred to one thousand horse-power is, in itself, one of no mean proportions. But these problems have been solved, and we may confidently look for the establishment of similar testing plants in other places.

Current Topics

To most minds, portability in the case of a machine tool carries with it the suggestion of relatively small size, and a 48-inch slotting machine, for example, would not ordinarily be thought of as a tool of the portable type. The advent of electricity as a motive power, however, has brought some of its striking results into this field as well as into others of perhaps better known character, and has given to some of the heavier machine-shop equipments a flexibility of application which has widely extended their sphere of usefulness and has correspondingly simplified operations of hitherto awkward nature. The possibility, through electric driving, of bringing the tool to the work instead of the work to the tool has, indeed, led to a degree of economy in the handling of material which, in one of the large engineering workshops, is the immediately striking feature of the place and at once commands attention. An overhead electric traveling crane picks up a heavy slotting, or shaping, machine, or drill press, or other tool of required kind, carries it the length of the shop, if need be, to the work in hand, and as promptly takes it away after its mission has been accomplished, to operate upon some other piece of work, or to make room for some other tool. That portion of the shop floor commanded by the crane is one huge work table, slotted and grooved in all directions for temporarily bolting down the tools, and the equipment in its entirety and the methods of handling it afford a splendid object lesson of evolution in shop practice. No time is lost in carrying the heavy piece of work from tool to tool to be adjusted and fastened for each separate one; it is left in its originally allotted place, to be operated upon by each tool in turn, or, preferably, by several tools at once, as is often possible, with a degree of ease, rapidity and precision which invariably is impressive.

THERE are preservative compounds galore for wire hoisting cables, and yet in their preparation and use they are generally thought of as little else than a sort of external protective covering to guard against rust. Indeed, a wire cable is rarely considered, as it should be, as a species of machine with many moving parts, each requiring lubrication to best fit it for its work. It is the internal lubrication of the various strands and wires which counts, and not the ordinary surface coating with any thick, tarry stuff, to which common usage seems to have given a stamp of approval. All this should be evident

enough when it is borne in mind that every time a rope goes over a sheave its many component parts chafe against one another. It is the friction so developed which must be counteracted, and it is only that kind of lubricant which will properly penetrate between the wires, besides having the several other attributes of a good lubricant, that will do the work. The nondescript surface coatings may be very expensive things to use.

As a matter of interest in connection with the much-discussed smoke nuisance, it is worth noting that smoke is not by any means a modern annoyance. About six hundred years ago, so Mr. Durfee said in recently speaking of the subject, when the population of London did not exceed 50,000, its citizens petitioned King Edward I. to prohibit the use of "sea coal," and he responded by making its consumption a capital offence. His successors, however, were more merciful to the users of coal, and its employment was resumed; but again, in the reign of Elizabeth, there were loud complaints against it, and, in 1661, John Evelyn, in his *Fumifugium*, laments that, "owing to the increase of coal smoke, the gardens no longer are fruitful." In the centuries that followed there were a number of parliamentary inquiries and some legislation intended to mitigate, if not remove, the evil, but, nevertheless, the consumption of bituminous coal has rapidly increased in London, and the inquiries and legislation relative to it have all ended—in smoke.

With the coming into prominence of acetylene as an illuminant, the availability of the gas as a gas engine fuel has been a matter of interesting inquiry, and some experiments have been made to determine its value in this new line of application. In one set of trials, conducted by Mr. F. Grover, of Leeds, England, of which particulars are given in a pamphlet issued by him, mixtures of air and acetylene were, as a beginning, fired at atmospheric pressure, and it was found that 1 part of gas and 18 parts of air were the weakest mixture that could be ignited. The pressure developed was about three times as great as when a similar mixture of coal gas and air was ignited, and the rate of combustion was much more rapid. When 7 parts of air and 1 part of acetylene were ignited at atmospheric pressure, the pressure developed was 111 pounds per square inch,—the highest point reached. On raising the initial pressure to 2 atmospheres, and igniting a mixture of 11 parts of air and 1 part of acetylene, the pressure developed was 197 pounds per square inch. On using the same mixture, and starting with a pressure of 3 atmospheres, the pressure developed was 350 pounds per square inch. Of especial interest is the statement that, with an initial pressure of 3 atmospheres, it was possible to ignite a mixture of 30 parts of air and 1 part of acetylene, the pressure developed being 180 pounds per square inch. The present cost of acetylene, however, Mr. Grover considers prohibitive for the general use of the gas for power purposes.

Thawing out frozen water service pipes by electric heat,—something that was done several times during the past winter,—is one of the latest accomplishments in applied electricity. The usual plumbers' methods of thawing out pipes are exasperating, if nothing worse, and the electric idea, which, by the way, appears to have been worked out simultaneously in several different places, comes to us, therefore, with the pleasing recommendation of neatness, dispatch, and effectiveness. With it excavating streets or grounds outside of buildings is not necessary. The operation consists in uncovering the service pipe after entering the building and cutting the pipe in two, so that electrically the water-pipe system of the building is cut out of circuit. Alternating current has been employed. One wire

of the secondary main of a transformer is connected to the end of the pipe to be thawed, where it is exposed indoors, and the other wire is connected to any convenient point of the water-pipe system that is exposed on the street, such as a fire hydrant or the next building's street-hose attachment, or nearest faucet. The current should be regulated to a safe carrying capacity of the pipe's least conductive point. The service pipe, if of the same carrying capacity throughout, will be uniformly heated, and in a very few minutes the ice will begin to give way. The whole thing is simplicity itself. As to the danger of electrolysis, there would seem to be little,—not enough to make it worth considering.

P. WALTER D'ALTON, who engineered the last of the Nordenfeldt submarine boats, and served in her in 1886 and 1887 until she was lost, condemns without qualification all submarine boats in a recent letter to the London *Engineer*. He tells us that the designing and building of submarine boats seems to be a sort of madness with one country after another, the only cure for which appears to be the actual running of the boats so designed and constructed; and then for a season the world is clear of talk of these impossibilities until the next country takes the fit, when the same enthusiasm is displayed, the same nonsense talked, the same mistakes are made, and finally comes the same relegation to the scrap heap of the object of all the hopes and enthusiasm. The submarine boat, with its crankiness, its absence of buoyancy, its danger,—to its friends,—is impossible as an engine of war, and, as Lord Charles Beresford said, "is quite useless as a fighting machine, owing to the necessary absence of morale amongst a crew which would be in a blue funk of it all the time." As partially submerged vessels, however, showing what undoubtedly are extremely small targets, and steaming at high rates of speed, boats of the submarine type may, at times, be ugly enemies to face.

BLASTING with high-pressure steam, instead of the usual inflammable explosives, is a proposition made recently by Mr. H. Schaw before the Institution of Mining Engineers, of Great Britain. Briefly, his suggestion, which has been prompted more particularly by accidents in coal mines from coal-dust ignitions due to the use of the customary explosives, is that a cartridge of water, lodged in a shot-hole, should be converted into steam at a pressure of about 150 pounds per square inch by means of electricity of low tension, and the cartridge or boiler to be made of such strength that it would burst at about this pressure, when the force set at liberty would break down the coal. Mr. Schaw found by experiment that it would be easily possible to boil water by the heat produced by a current of electricity passing through a platinum wire similar to that used for firing mines immersed in water, and is of the opinion that at the moment when the boiler or cartridge bursts, the wire will fuse and the electric circuit will be broken, and no risk of ignition of firedamp or coal-dust will remain from the heated wire. Under the supposition that the force developed by the water cartridge would be sufficient to break down the undercut coal in a mine, Mr. Schaw thinks that the practical working of the proposed method would present no great difficulties, and that it would be perfectly safe in any coal-mine; and this is its only recommendation, for it certainly would be more expensive and troublesome than the usual methods of blasting.

THE general opinion of the public, when a boiler explodes, is, that unless the engineer allowed the water to run low, the cause of the explosion is a mystery. Whether the boiler was strong enough to hold the pressure, appears to be a point to which no particular importance is attached. As a matter of fact, it is a mystery why more boilers do not explode. For example, the *Locomotive* recently printed a story of a boiler which ought to have ex-

ploded long ago, according to all reasonable lines of argument and methods of prognosis; yet it is still running, after nearly half a century of service, the total outlay for repairs during all that time having been an old-fashioned copper coin. About 1853 Mr. Chauncey Pease, of Cooperstown, N. Y., so the story goes, had a steam boiler built in New York city, by some one whose name is long forgotten. It is a horizontal tubular, with a dome, and is rated at 15 horse-power. It is 9 feet long and 36 inches in diameter, with thirty-seven 2-inch tubes. It is made of iron, in three courses, and single-riveted, with the rivets pitched two inches from centre to centre. There is no glass water-gauge on it, but there are three try-cocks. When it was to be installed, it was sent by rail to Fort Plain, N. Y., and transported thence by teams over the country to Cooperstown (a distance of perhaps 30 miles), where it was in use two years by Mr. Pease. It was then sold to Messrs. Barnes & Fox, who moved it by team to the town of Maryland, on the Delaware and Hudson Railroad, some 15 or 20 miles from Cooperstown, and used it for ten years in a sash and blind factory. At the end of this time Mr. F. M. Fox, the present owner, bought the factory, and moved the boiler a few miles to Colliersville, where for thirty-three years more it has done service in his sash and blind factory, and is still in daily use.

——

THIRTY years ago it leaked slightly, where the dome was riveted to the boiler. The hole was hardly large enough to insert a fine knitting-needle, and Mr. Fox enlarged it to a diameter of one-eighth of an inch, and plugged it with a copper rivet made from an old-fashioned copper cent. With this exception, no repairs have ever been made on the shell or tubes of the boiler. The fuel with which the boiler has been fired has been the waste of the mill, with a little coal when there was not waste enough for that purpose. The safety-valve has been kept set at 80 pounds, but the actual pressure used in all these years has been (and is still) 60 pounds. No one has been inside the boiler, except on one occasion, some eighteen years ago. It is cleaned out as well as it can be without getting into the boiler every three weeks, the tubes being cleaned oftener. There has never been a regular engineer caring for the boiler; it has had all its attention from the proprietors and the men about the mill. The first engine used with it was of ten horse-power, but a change was made thirty years ago and a thirty-five horse-power engine substituted, running at 60 strokes to the minute, under 60 pounds of steam. After a time Mr. Fox modified the engine so as to make it run at 90 strokes to the minute under 60 pounds of steam, and it is now working at this speed under the personal supervision of Mr. F. M. Fox, who is hale and hearty at nearly seventy years of age. This history has been given at some length in order to show what boilers will do,—sometimes. On the other hand, instances might be related in which men were killed and maimed, and much property was destroyed, by boilers only two or three months old, and which were supposed to be in perfect condition. It is the old story of the unexpected which often happens. Boiler explosions do not always occur when we think they ought to, and they often do occur when common reasoning would indicate that they ought not.

Dr. Nansen Mrs. Nansen Lord Kelvin Lady Kelvin

FROM A PHOTOGRAPH BY MESSRS. MACLURE, MACDONALD & CO., GLASGOW

(See Page 133)

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CASSIER'S MAGAZINE

VOL. XVI. JUNE, 1899 No. 2

THE ELECTRIC RAILWAYS OF BUDAPEST

By Alfred O. Dubsky

A CAR FITTED WITH BOTH OVERHEAD AND UNDERGROUND TROLLEYS

BUDAPEST is not only the capital of Hungary, but it is its trade centre as well. The river Danube flows through it, and railways radiate from it, and ship and railway traffic together have long made it one of the busiest places in the kingdom. With a population of over 620,000 the city, like others of its proportions, had the transportation problem forced upon it years ago, and electric traction in its earliest days received there a degree of favourable consideration which gave the municipality a prominent and interesting place among electric railway pioneer towns. In fact, the Budapest electric slotted conduit road will ever be considered a distinctive achievement in electric railway history.

At the present time the Budapest

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A CAR ON ONE OF THE CONDUIT LINES

AN OVERHEAD TROLLEY LINE

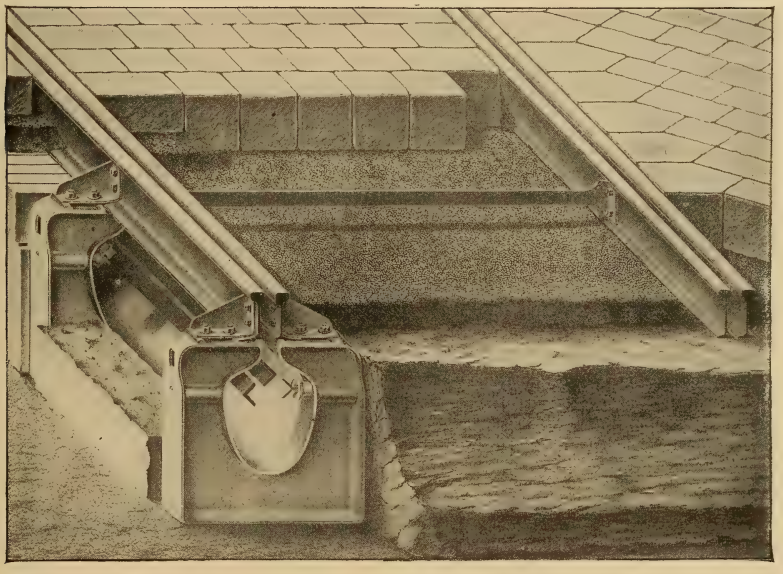
electric railway system comprises about 104 miles, and has been installed, properly speaking, by four independent companies. The oldest electric railway of Budapest, the so-called Metropolitan Railway, is made up of about 31 miles of road; the double-track Budapest-New Pest line was built some years later, and is about 12½ miles long; the Francis Joseph underground railway,—a double-track road about 2⅓ miles long,—was opened during the well-known Hungarian Millenium Exhibition; and, finally, there is the Budapest Street Railway Company, with about 58 miles of road, which was the latest to put in electrical equipment.

The Metropolitan Railway is of special interest, for it was on this that the underground trolley or conduit system was first employed with satisfactory results, from both engineering and financial points of view. The first conduit lines were built in 1889 by Messrs. Siemens & Halske, of Berlin, who sold them to the Metropolitan Railway Company in 1891, but since that time important additions have been made to the system.

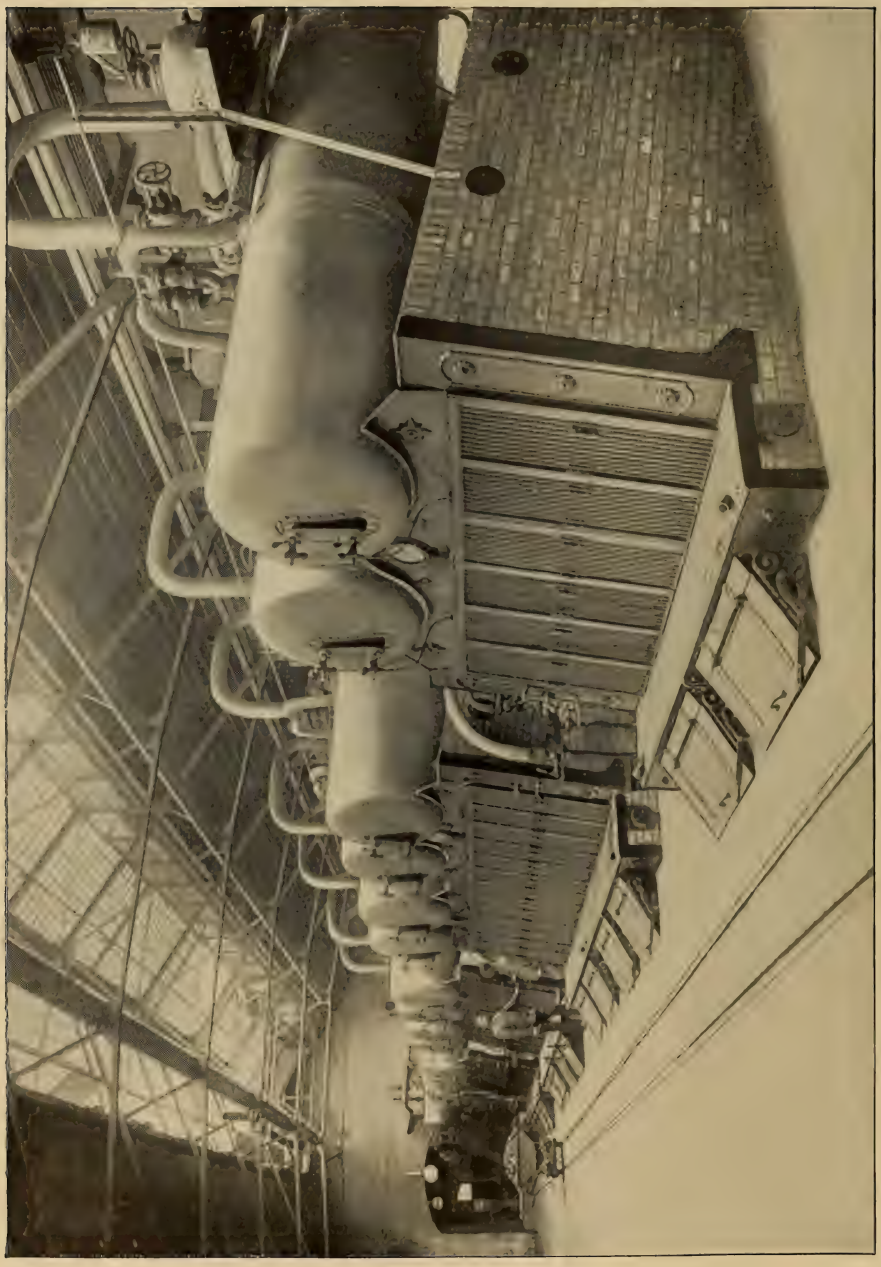
The underground trolley conduits in use on these lines have already been referred to in CASSIER'S MAGAZINE for April, 1897. Two angle-irons are put into a conduit under the street surface and serve for both supply and return of the electric current. Both conductors are fixed on insulators carried by cast iron frames, or yokes, about 4 feet apart. These yokes inclose the conduit, and are shaped as shown in the illustration on this page. They form also the foundation for the double rails, and the space between these forms the conduit slot.

The greatest width of the conduit is 11 inches, and the greatest height, 13 inches, while the slot is about an inch wide. The bottom of the conduit is 22½ inches below the upper rail surface. The surface water which may find its way into the conduit is collected in special pits at one side and from these it is discharged into the sewers.

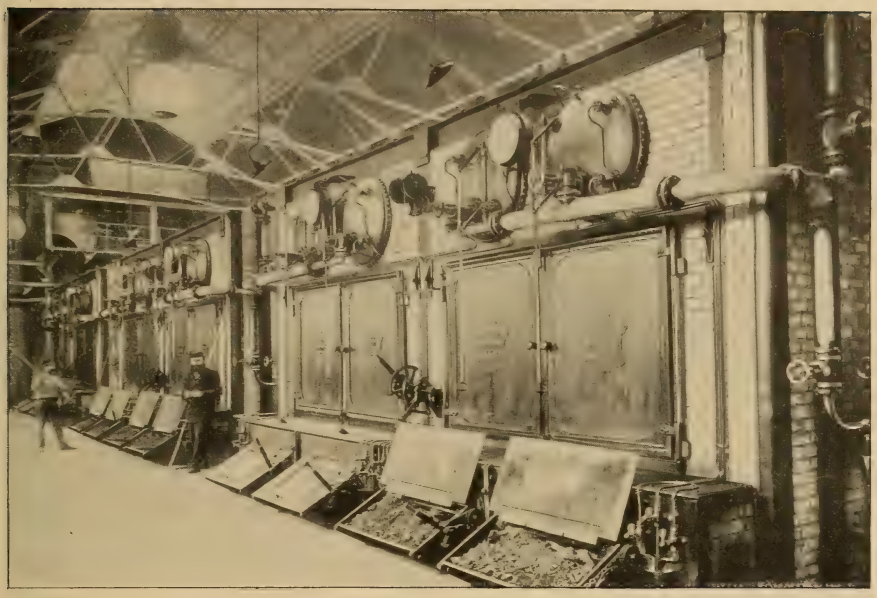
The rails are of the so-called Haarmann type, and while the two slot rails are secured to the cast iron yokes by means of angle-irons, as shown, the other rail is laid simply upon the well-stamped ground, and the gauge is maintained by suitable cross-connections.



A VIEW OF THE ORIGINAL CONDUIT

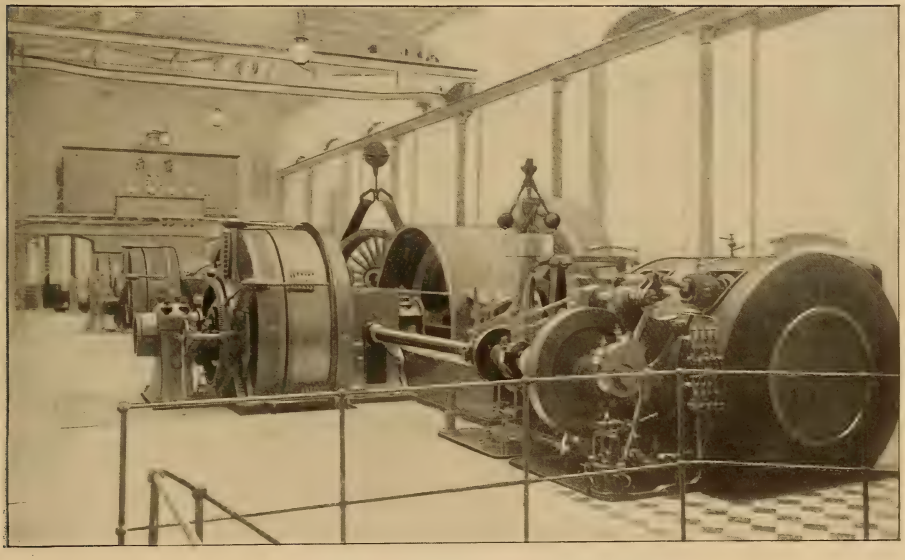


THE BOILER HOUSE FOR THE FRANZ-JOSEF UNDERGROUND RAILWAY. EQUIPPED BY MESSRS. SIEMENS & HALSKE, BERLIN

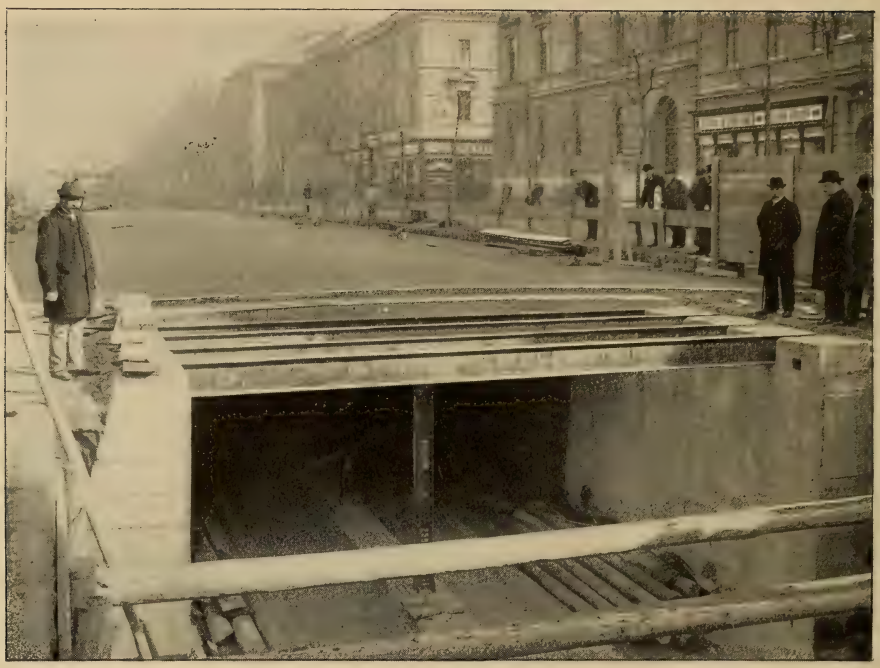


BOILER ROOM OF THE BUDAPEST STREET RAILWAY COMPANY

This conduit system has been working for about nine years, and during this time has given entire satisfaction. The line is, however, not without defects, due to the fact that when it was put down there was no previous experience in conduit construction to fall back upon. There is, for example, the disadvantage that the insulators are accessible for repair only by tearing up the pavement and disturbing the conduit. The angle iron conductors, too, can be removed from the conduit only by taking up the two slot rails so as to make



THE GENERATOR ROOM OF THE UNDERGROUND RAILWAY



SOME OF THE UNDERGROUND WORK ON ANDRASSY AVENUE

ONE OF THE UNDERGROUND STATIONS

a greater width of slot available, and the plough, or current collector, is so inclosed by the conductors that it cannot be withdrawn without breaking it or destroying a portion of the conduit. The cleaning of the insulators, which is very important for any underground trolley system, cannot be effected except in a very uncertain way,—by sprinkling water into the conduit where the insulators are supposed to be.

The Metropolitan Railway Company operates four lines having underground

A STATION ENTRANCE FOR THE UNDERGROUND ON GISELLA SQUARE

trolleys, and three lines, about 14 miles long, equipped with the overhead trolley. The feeders for all these lines branch from the central station in the Gaertner Strasse, and are lead-covered cables of Siemens & Halske make. The station has been enlarged several times owing to the continually increasing traffic requirements, and furnishes current also for the already mentioned underground railway.

The boiler plant comprises 13 water-tube boilers, while the engine room contains 10 steam-engines of various sizes and of a total output of 2800 H. P. They are all horizontal, compound condensing engines.

The generators are direct-connected, and have a total output of 6200 ampères at from 300 to 320 volts. This low tension is probably a natural consequence of the bad insulating conditions in the underground conduits, but is not economical, for very considerable copper quantities are demanded for some lines branching off for some distance from the station and carrying heavy loads. All the generators were built by Messrs. Siemens & Halske. During the hours of light traffic, with a correspondingly diminished load, they deliver into a storage battery system.

The average speed of the cars is about 9⅓ miles an hour, but beyond the city limits it is increased to a little over 11 miles. Under these circumstances each car makes a run of 94 miles during 16 hours of work.

The lines of the Budapest Street Railway Company are on both sides of the Danube and comprise 15 miles of con-

duit road, while 43 miles are equipped with the overhead trolley. Current is supplied from two stations on opposite sides of the Danube. One of these stations is fitted up with two generators of 600 H. P. and two of 300 H. P., each direct-connected with a horizontal tandem compound engine. In addition two boosters are provided for the supply of distant points on the line during the hours of heavy traffic. Babcock & Wilcox boilers furnish steam.

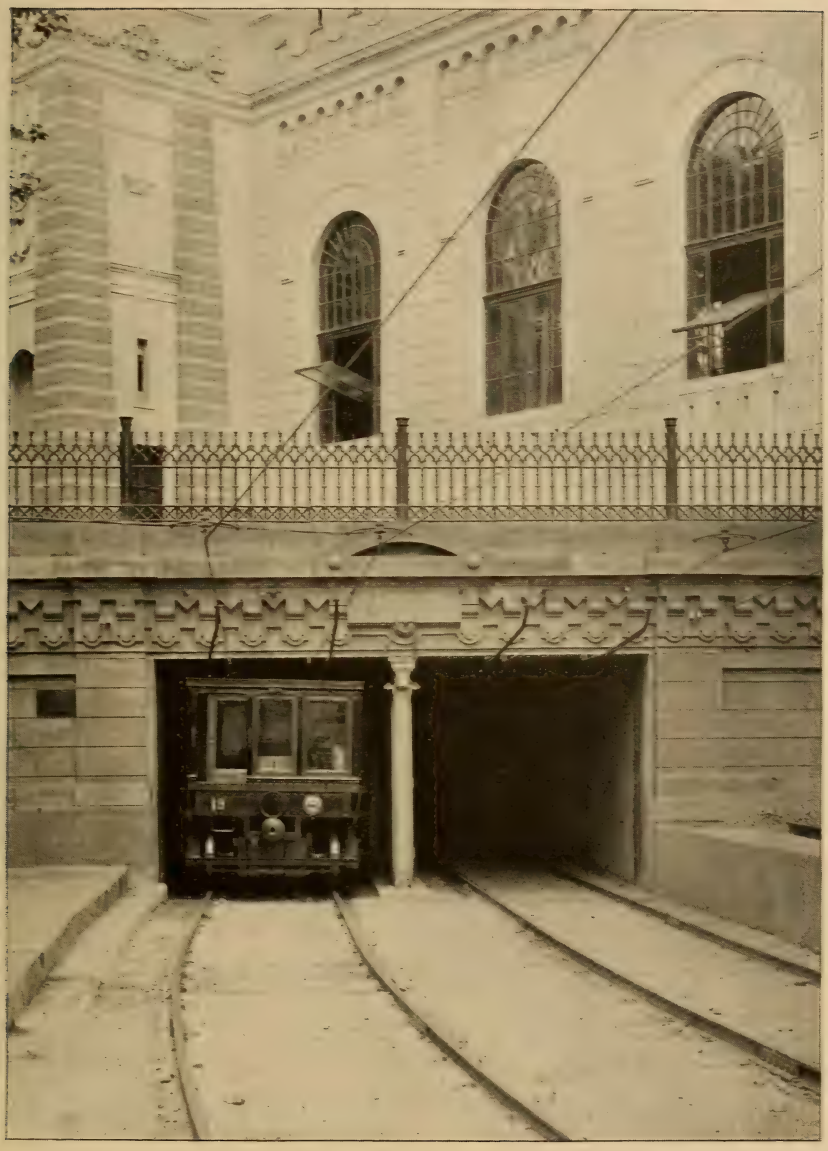
The second station contains four steam dynamos of 700 H. P. and also two boosters, while the six boilers again are of Babcock & Wilcox make. The electric equipment of both stations and cars was furnished by Messrs. Siemens & Halske, while the engines and the cars themselves are of Hungarian make.

The same system of underground trolley conduit as on the Metropolitan Railway is here in use, though some improvements have been introduced. Small iron T-rails, for example, are used as conductors instead of angle-irons, and they are of small enough size to pass readily through the conduit slot. The insulators, too, are accessible through hand holes, and can thus be conveniently reached for cleaning or repairs. The whole track and conduit construction, in fact, shows the teachings of experience.

The overhead trolley lines all have sliding bow contacts of the kind shown in some of the accompanying illustrations. In this respect the cars present a striking difference in appearance as compared with British and American ones. The cars, too, are designed to work with the overhead trolley as well as on the conduit sections, and the necessary change in connections is very quickly accomplished at the change-over stations, at which a man is specially detailed for this purpose.

The third electric street railway of Budapest, namely, the Budapest-New Pest Railway, is considerably smaller than the two foregoing tramways. It connects Budapest with two of its suburbs, and in one sense is not a street railway at all, as it is laid on an embankment specially put down for it. The average speed on this line is greater than on the other tramways,—about 16 miles an hour, including stopping at the stations. The overhead trolley wire is in use on its whole length of the track, but instead of bow contacts, the more familiar small trolley wheel is employed. The railway crosses the lines of the Hungarian State Railway twice, in one

ONE OF THE CARS OF THE FRANZ-JOSEF ELECTRIC UNDERGROUND RAILWAY



THE TUNNEL ENTRANCE AT THE "STADWAELDCHEN"

case through a tunnel, and in the other by means of an iron bridge, so as to avoid grade crossings.

The power station supplies a 440-volt current, and the equipment consists of five vertical compound steam-engines, each of 160 H. P., coupled directly to their dynamos. The electric machinery and material were furnished by Messrs. Ganz & Co., of Budapest. This is true also of the cars, of which there are thirty, supplemented by two 50 H. P., locomotives which are used for freight service and for auxiliary passenger service on days of particularly heavy traffic.

The total length of the road is about 12½ miles, and the power station is situated outside of the city itself,—practically at the centre of distribution.

STATIONS ON ARENA STRASSE FOR THE UNDERGROUND RAILWAY

A STATION ON FRANZ DEÁK SQUARE

Andrássy Avenue is the most imposing thoroughfare of Budapest, flanked by the most pretentious of the city's private and public buildings. It leads also to the "Stadtwaeldchen," the city's favourite park. The plan of building a tramway along this street had been under consideration for more than twenty years, but the project always met with much opposition, as it was declared to be a sacrilege to disfigure the street by such a structure.

An underground railway, however, was evenutally considered as a satisfactory substitute for a surface line, and in 1894 the plans for such a road were taken in hand.

In 1896 the road was completed and ready for service. Strictly speaking, it is not a tunnel railway, but lies immediately beneath the street surface, with a structural steel roof. The road in its entirety is somewhat over two miles long, and of this length only a little over a quarter of a mile is underground. At the "Stadtwaldchen" the line emerges from the tunnel and from there on it continues as a surface road.

The clear height of the tunnel, if it may be so called, is only about 9 feet, and its extreme width about 20 feet. There is a double track with a line of central roof pillars between the two. From the street surface above to the rail level the distance is not more than 11 feet 9 inches at any point. The side walls and bottom of the tunnel are made of beton, and this is true as well of the roof, though the beton in that case is filled in between the steel beams which form the essential supports for the street surface. Probably the best general idea of the character of the construction may be gained from the upper illustration on page 96, reproduced from a photograph taken while the work was in progress.

Current for operating the line is supplied from the power station of the Metropolitan Railway. The road is, in effect, a double-trolley road, the supply and return circuits being provided for by two T-shaped iron rails fixed to the tunnel roof over each track. Electricity for lighting the tunnel is supplied by a special dynamo, thus making the lighting and the power circuits quite independent of each other.

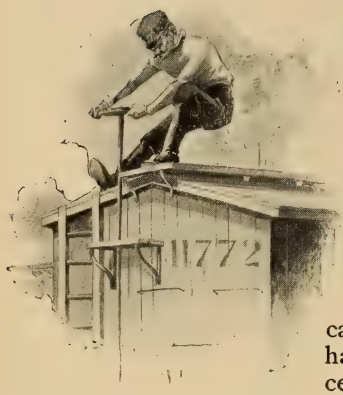
The comparatively small tunnel section available made the problem of designing the cars a somewhat difficult one. Indeed, there was scant space available for the motors and trucks, and the result was the rather unusual structure shown in the illustration on page 98. There are altogether twenty-one of these cars running at three minutes' headway, at a speed of about 25 miles an hour.

The station platforms are built on both sides of the tracks, and the stairways leading up to the street level terminate in artistically executed kiosks, examples of which are given on the opposite page and on page 97.

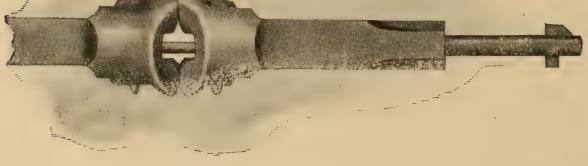
With all the hastiness of this glance at electric transportation in Budapest one cannot resist the conviction that much has been done there in this line. Indeed, the city has well demonstrated its enterprise in electric tramway matters, and its original slotted conduit road will always be remembered as the practical fore-runner, the first practically successful example, of roads of this type.

THE AUTOMATIC FREIGHT-CAR COUPLER IN THE UNITED STATES

By H. G. Prout, Editor of "The Railroad Gazette," New York.



AT the end of June, 1889, about six per cent. of the freight cars in the United States were equipped with automatic couplers. By January 1, 1899, the proportion of cars so equipped had risen to 77 per cent. These couplers are all of the general style known first as the Janney type, and now usually called the Master Car Builders' coupler. The progress in the introduction of the automatic coupler has, therefore, been reasonably fast, particularly if we turn the percentages into absolute numbers and so get some notion of the enormous expenditure that has been made. The cars equipped before 1889 were 80,150 in number, and by January 1, 1899, they were 898,281.



THE OLD LINK AND PIN COUPLER

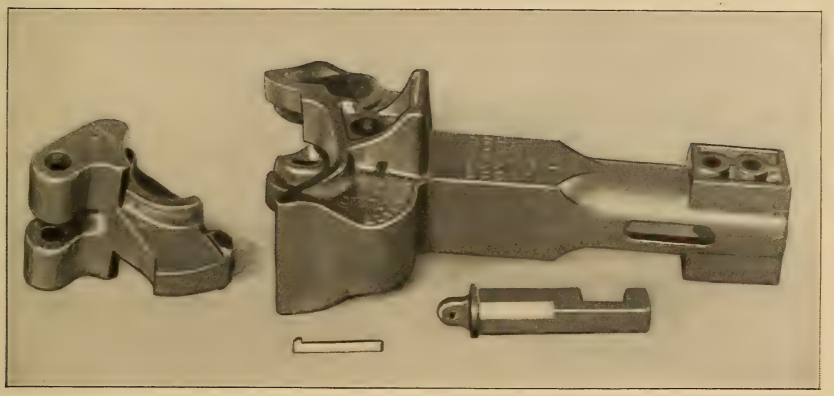
The movement was very steady up to 1896. If plotted, it would have made almost a straight line. From 1896 to 1897, however, it jumped from about 37 per cent. to about 58. That was the year of the greatest progress. The work still goes on, and the Interstate Commerce Commissioners, in their latest annual report, speak of "the probability of full provision of automatic couplers on January 1, 1900." "Full provision" means the equipment of all freight cars used in interstate traffic; but this means practically the whole freight rolling stock, excepting only a small number of cars used in special services.

This quick development of the automatic freight coupler did not begin with legislation, but it has probably been accelerated by the various State and federal laws. It would be impossible to say with any accuracy when the agitation for automatic freight car couplers began, but it must have been early in the history of railroads. We find signs of it almost at the beginning of the Master Car Builders' Association, and in 1874 a committee of that association spoke of the great advantage of a uniform draw-bar which should also be a "self-coupler." But the committee said that none had yet been invented which could be considered at all practical. In that year some member of the association spoke of the disappearance of the so-called automatic couplers of 30 or 40 years before.

In the decade from 1870 to 1880 more stress was laid upon uniformity than upon automatic coupling. It was realised that many men were killed and injured in car coupling, but that most of these accidents came from the fact that the draw-bars brought together varied in height from the rail. We have no statistics of the number of train hands and yard hands who were killed

June 1899

and injured in the early seventies, but railroad officers and others had begun to talk of this as a serious matter. In 1882 it was estimated that from 1200 to 1500 employees were killed every year, but there was no attempt in this



THE "STANDARD" MASTER CAR BUILDERS' COUPLER, SHOWING THE KNUCKLE, DRAW BAR AND LOCKING PIN

estimate to differentiate between those killed in coupling accidents and those killed in other ways.

No class of men in the community felt so keenly and seriously the importance of saving railroad employees from accidents of this kind as did the officers of the railroads themselves. These men realised, as nobody else could, the suffering among the men and their families, and the pecuniary loss to the railroads. The burden of paying physicians' bills and wages during disability, and otherwise helping the injured men or their families was, in itself, a serious matter. In those early days, too, the professional "friend of man" had begun to agitate the matter in the public prints and in the lobbies of the legislatures, and railroad officers of reasonable foresight were anxious to anticipate legislation.

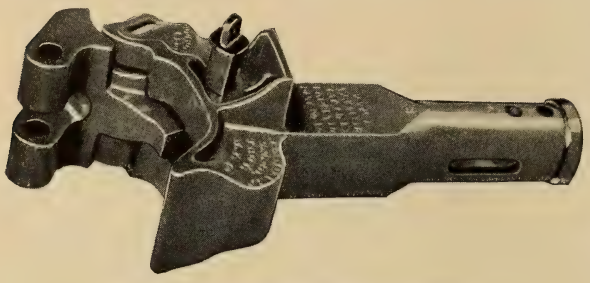
Another financial point had also arisen in the heavy expense of maintaining the link-and-pin coupler, for the loss of the loose pins and links was a serious matter. In 1875 figures collected from the railroads showed this item alone to amount to sums varying on different lines all the way from $18,000 to $60,000 a year, and in 1876 there appears in the reports of the Master Car Builders' Association an endorsement of the Janney coupler.

The serious work in the Master Car Builders' Association may be said to have begun about 1882, when a committee made a specific report, although very brief, on automatic draw-bars, and recommended that the subject be referred to the executive committee for further action. Here it may be as well to say that the Master Car Builders' Associaton is the one authoritative technical body of railroad officers which took up this problem and worked it out, and finally caused the adoption of the automatic coupler now in use in the United States. The action of the American Railway Association was to endorse and confirm what the Master Car Builders' Association had done. Those who have read the report of Mr. Hopwood, secretary of the railroad branch of the Board of Trade, will see that in his recent visit to the United States he was misled as to the relative position of the associations in this matter.

It may be as well also to say here that the Master Car Builders' Association is what its name indicates,—a body of officers charged specifically with rolling stock affairs. The American Railway Association is a body made up of presidents, vice-presidents, general managers and general superintendents,

and naturally covering a broad field of railroad administration, but not dealing technically with rolling equipment.

In 1884 one of the great steps was taken in the development of the coupler. In that year Mr. E. B. Wall introduced a motion at the convention of



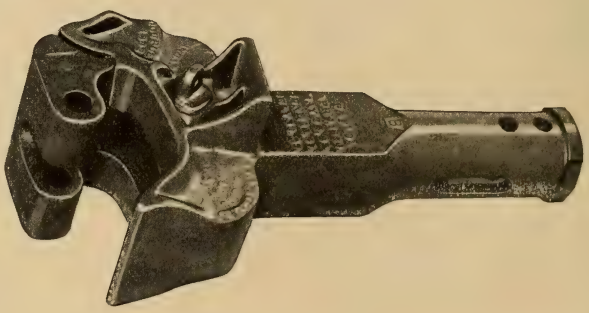
THE COUPLER OPEN, READY TO COUPLE

the Master Car Builders' Association to the effect that it was the sense of the convention that the best coupler, mechanically, is one which performs the coupling along a vertical plane, and this motion was carried. This was a turning point. It at once fixed a principle for the further development of the automatic coupler and ruled out the consideration of the link and pin.

The fundamental notion was that the surfaces of two couplers in contact should be free to move over each other in a vertical direction. Thus the contact could be close, but at the same time allowance could be made, in the coupler itself for a difference in height of two draw-bars coming together. This seemed then, and seems now, to be necessary, for obviously the height of draw-bars must vary considerably, dependent upon the condition of the springs and upon the loading of the cars. This action did not bind any of the railroads which were represented in the Association to use what came to be known as the vertical-plane coupler or to discard the link coupler, but it committed the association to work for the development of the coupler along certain restricted lines.

In 1886 important progress was made. A committee of the association examined and tested 44 different couplers which were presented to them, and recommended 12 of these for further trial. This helped matters by still further narrowing the field. But the committee were obliged to report that they had grave doubts whether there was then any automatic coupler which any one railroad company would be justified in putting on its cars. Other companies would inevitably use other couplers, and the danger to trainmen would be increased rather than diminished, and the cost of maintaining the couplers would be greatly increased. And so it seemed to the committee the best course for the railroad companies to continue to use the prevailing link and pin coupler until experiment and service should have still further narrowed the field. It was recommended that the energies of the association be especially devoted to reducing to something like uniformity of style and dimensions the link and pin draw-bars and the buffing blocks used on the ends of cars.

In 1887 great progress was made. The executive committee came into the convention with the report that the coupler question was "certainly the knottiest mechanical problem that had ever been presented to the railroads." Over 4000 attempted solutions of this problem were on record in the Patent Office. The great difficulty of the com-



THE COUPLER CLOSED

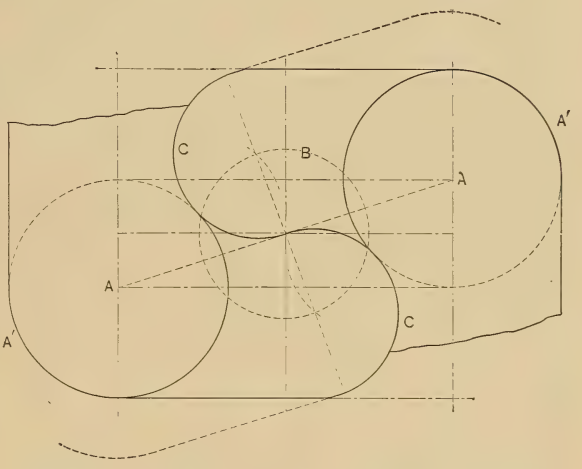
mittee had been to find even one which did not possess grave disadvantages. The question of strength alone was found to be serious, and the committee was in doubt if the solution of the coupler problem would not "ultimately require the invention of an entirely new material."

By this time the action of the legislatures of various States of the United States had come to be a further serious complication of the subject. Laws had been passed in various States requiring the railroad companies to put on automatic couplers. The laws generally left the State Commissioners to decide what coupler a railroad might use, and these commissioners had approved of 34 different couplers, and the confusion of the subject seemed to threaten the extermination of the men who had actually to deal in the yards with these inharmonious devices.

But before the convention of 1887 adjourned two things happened which had a very important bearing on the development of the coupler. The first of these was the report of the discovery which had been made at the trials of the air brake, shortly before, that a freight train could be handled better with close coupling than with slack coupling. This was astonishing to the majority of railroad men, but careful experiments at Burlington, Ia., had proved it. This discovery was an important factor in finally putting the link coupler out of use.

The other great event of the 1887 convention was the recommendation for the adoption of a coupler of the Janney type. The executive committee brought in such a recommendation and the convention voted to pass it on to letter ballot by the association, and when the ballot was canvassed it was found that the recommendation had been adopted. This step was only second in importance to that which was taken in 1884 when the convention was persuaded to adopt the principle of coupling in a vertical plane.

This action did not, however, fix the contour of the coupling faces. The Janney type might mean almost any coupler in which the engagement between cars was made by a loose knuckle swinging about a vertical pivot in the head of the draw-bar. The executive committee now proceeded to determine what the lines of the engaging face of the coupler should be. This was a vital point, because all couplers must be not only vertical-plane couplers, and couplers of the Janney type, but they must couple freely and securely with each other.



METHOD OF CONSTRUCTING THE WORKING FACES OF THE JANNEY COUPLER

The sides of the square are 6 inches. The centres *A A* are taken at 2 in., respectively, from the top and bottom of the square. The circles *A' A'* are struck with 2-inch radius and these define the pivot portion of the knuckle. The inner circle *B* has a radius of 1½-in. From its intersection with *A' A'* arcs are struck cutting *B* in two points. These intersections determine the centres of the semi-circles *C C* which form the ends of the respective knuckles. These semi-circles and the circles *A' A'* are joined by tangents and short arcs struck from the centre of the figure.

The committee reached the conclusion that the "principle of contact of the surfaces of vertical cylinders embodied in the Janney coupler affords the best connection for cars on curves and tangents." But the lines of the Janney coupler embodying this principle were covered by patents. Here was a difficult situation. It would not do to

TWO CARS EQUIPPED WITH JANNEY COUPLERS COMING TOGETHER FOR COUPLING

adopt a coupler which would throw all of this colossal business into the hands of the owners of a patent. Indeed, it would be impossible for the association, whatever action it might take, to compel the railroads to buy and use such a coupler; the railroads would refuse to be put in such a position. This difficulty was cleared away by the very sagacious action of the owners of the Janney patents, who agreed to waive their claims to the lines covered by their patents for all railroads represented in the Master Car Builders' Association, and this meant practically all of the railroads of the United States.

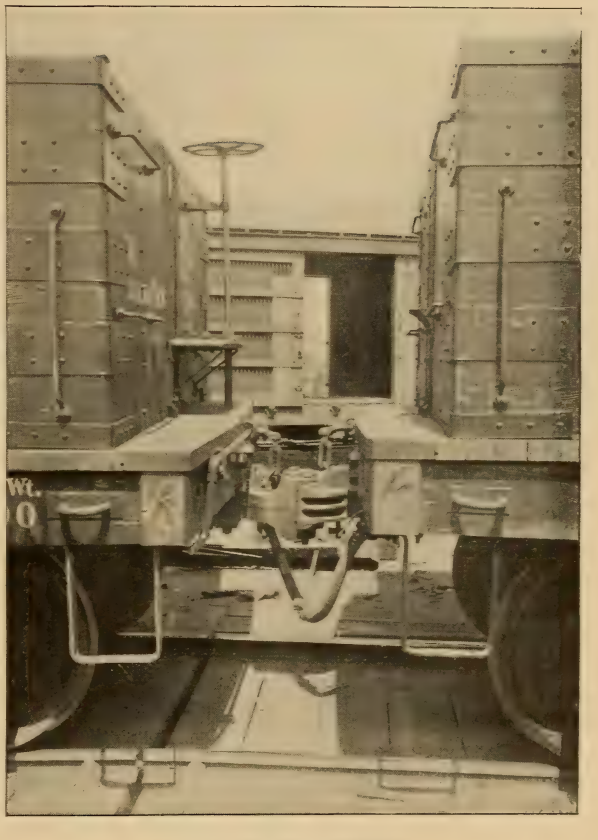
The way was now clear. Inventors could go on and make all sorts of modifications in the locking gear and in the dimensions and forms of the knuckles and of the heads of the couplers so long as these met the requirements that the coupler should be of the Janney type, that the contour of the engaging faces should be on the Janney lines, and that the couplers should work together. All that has happened since 1887 has been to develop the automatic coupler along the lines then laid down. Many different couplers have been designed, patented, made, sold and used, but they have departed from the Janney coupler only in the disposition of the material; in the kind of material used; in the locking and unlocking gear; in efforts to make the knuckle open of itself when released, and, unfortunately, in deviating from the strict lines of the engaging faces. Details have been improved in most of these couplers, but their efficiency in action has often been impaired by failure to stick close to the original lines. In general, the material used is malleable iron for the main member or draw-bar, and wrought iron or cast steel for the movable member or knuckle, but cast steel is used also for the draw-bar in some cases.

Such is a bare outline of the work of the railroad officers who, in the Master

Car Builders' Association, made the coupler revolution. To appreciate this work, one must have been in it. Little but results appears in the records. The real work was done in committees and outside of the convention halls. The struggle was long and often bitter, and had its dramatic episodes. The natural and proper caution of men who were charged with great financial interests worked against the new movement. There were automatic, or so-called automatic, couplers of other types which had their strong friends. No doubt there were a few members of the association who had a direct money interest in keeping the door open for the use of one or another of such couplers. It would have been wonderful if this had not been so. Then there was the inevitable proportion of honest stupidity which always sits back in the breeching. It took persistence and tact to work steadily on through the years and at last to succeed against all these influences.

It would be hard to divide justly the credit for the victory among the men who secured it, and this would be a delicate thing to attempt. But probably it will be agreed that the late E. B. Wall did more to bring about the result than any other one man. British engineers and railroad officers will soon have an opportunity to learn the history from another man who helped to make it and who is now going to live among them, Mr. Cloud. The names of Mr. Forney and Mr. Rhodes must also have an honourable place in the complete history of this episode.

The legislative history of the movement was of little interest until the Federal act was passed in 1893. The State laws simply confused the matter by authorising the use of a score or two of couplers which generally could not have been made to work together. The Federal act of 1893 provided that cars running in interstate service must be equipped with automatic couplers before January 1, 1898, but gave to the Interstate Commerce Commission power to extend the time for cause, and the commission has extended the time until January 1, 1900. No doubt the presence on the statute books of this Federal act has recently done a good deal to expedite the work of equipping freight cars with an automatic coupler.



THE SAME CARS COUPLED

What have been the net results of all this? The cost to the railroads cannot be estimated. In many cases it was only the difference between the first cost of a link-and-pin coupler and of the M. C. B. coupler. In other cases, when cars were shopped for repairs, the old coupler was taken off and the new

one put on. It is not possible to determine the numbers of the automatic couplers which have gone on as new equipment or as replacements.

From the latest statistics of the Interstate Commerce Commission it appears that the accidents to train hands in coupling have decreased 50.6 per cent. as compared with 1893. But in the same time all accidents to employees fell off 37.9 per cent; and in the same time the average intelligence of employees doubtless rose, for owing to the decline in business many men were discharged, and naturally the best men would be kept.

The testimony of the men who work in switching yards is conflicting as to the relative safety of the old and new couplers. But there are two great facts which vitiate the statistics and the observation of the men:—

(1) Up to the beginning of 1898 only about 67 per cent. of the cars had the M. C. B. coupler; up to the beginning of 1897 only about 58 per cent. The old and the new couplers were, and still are, mixed in the trains, and the dangers of coupling mixed trains are greater than with straight trains of either kind of coupler.

(2) The unlocking gear is often defective in design, or construction or maintenance. This is a fruitful cause of annoyance and danger.

Both of these conditions will soon disappear; and only then may we expect to get the full advantages of the Master Car Builders' coupler in safety and convenience.

Statistics of the relative cost of maintenance of the old and new couplers are still as imperfect and unreliable as the casualty statistics, and for the same reasons. Unquestionably, in the maintenance of the coupler alone the new one is considerably cheaper. The losses of old, loose links and pins alone cost more than the whole up-keep of the new coupler. On the other hand, there is sometimes complaint that in drilling cars (marshalling) the men abuse them more when they are fitted with automatic couplers.

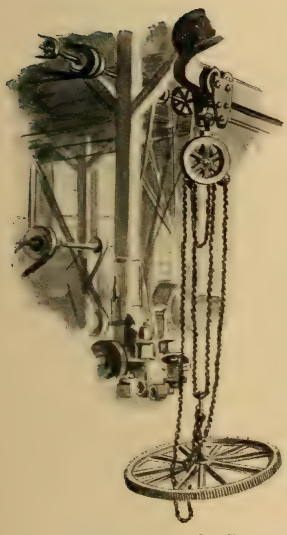
Still other complications exist, for we are yet in the period of transition and evolution. Many couplers have been put on with bad locks, and many others which do not conform to the standard lines and dimensions, and others with knuckles made of weak material. Such defects have led to difficulty in coupling and to parting of trains. But these are matters of good or bad administration, and are not fundamental.

Finally, by judicious sophistication of testimony it is easy to make out a better case for the Master Car Builders' type of coupler than has been made here; or a worse case against it. But the great fact remains that it is the standard of the United States, and must, in the nature of things, remain so for many years to come. And, further, any mechanical engineer, looking at the two couplers candidly and with competent judgment of mechanical contrivances, and knowing the conditions of railroad working in the United States, must admire the wisdom and resolution of the men who selected the new type and forced its adoption. It by no means follows that the American coupler would suit British conditions. These are very different from the conditions which existed in the United States.

MANUFACTURING ECONOMIES

Some Short Cuts in American Shop Practice

By Henry Binsse



ABOUT two years before the Columbian Exhibition in 1893, a meeting of the European and American engineering societies was held at Chicago. A day was given to a visit to the works of the Illinois Steel Company which had just been rebuilt. Among the many distinguished visitors was a group composed of the foremost engineers of Great Britain, France, Germany and Sweden. They had been shown over the various departments, as the guests of honour, and finally came to the new roll train. Great ingots of glowing steel were being withdrawn from the furnaces, transported to the enormous rolls and there drawn out, in a few passes, into rails ninety feet in length, the entire operation being the work of a few minutes, and each rail following closely upon the one before without the loss of a moment's time.

To him who could possess himself enough to observe and to think in the din, clatter, glare and heat, the most striking feature of the bewildering scene was the small number of men, working and controlling, with absolute certainty, the colossal machines which were engaged in fashioning the masses of steel. Familiar as these Europeans were with this, the special study of their lives, they were carried away by the perfection of the machinery, and admitted that they had never seen the like. One, a German, by the way, turned to the American engineer who was acting as his guide, and said, "This is the sublime in machinery."

From this period and, later on, from the Columbian Exhibition dates, it may be said, the almost universal acknowledgment that the United States holds the leading position as the master in developing and guiding nature's forces by machinery.

Now the interesting question comes of itself to the mind, where shall we find the causes which have brought the United States, almost unawares, to the advanced position, which others will certainly strive by might and main to reach, and which can be kept only by putting forth the greatest efforts?

It would be foolish to suppose that this success is owing to any superior quality of mind. In that respect, all civilised countries are equal. If Americans build superior machines and excel in knowing how to reach certain results by machinery, it is because their mental activity in that line has been developed by facts or conditions peculiar to their country.

In mechanical engineering success hangs very largely, if not principally, upon the details being right. Broadly speaking, every builder has the same general plan for the pump, steam engine, machine tool. Superiority in these is a matter of having the best details. It happens every day that a machine fails utterly with one set of details, to be made a great success later on by some one who possesses a clearer insight into the practical difficulties in the way, and has sufficient knowledge to

overcome them by better designed parts.

Moreover, there are two distinct points from which to study machinery details,—that of the construction most suitable to make the machine efficient; the other to have it constructed with economy. Broad capacity of this kind comes from practical experience, and good mental perceptions to begin with, and it is the very foundation for excellence in mechanical engineering.

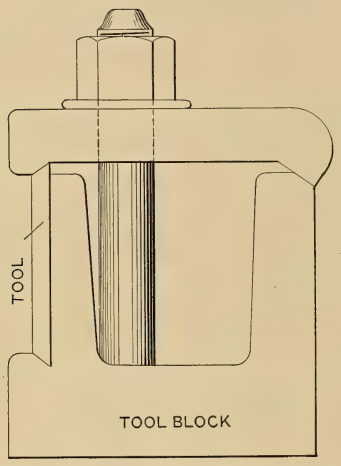


FIG. 1.—A HOLDER FOR A CUTTING-OFF TOOL

Therefore, the best results may be looked for in machine building where we shall find the closest union between the designer and the workman. The ideal condition would be to have the workman take the same lively, keen interest in the work as the designer or the master. "L'Union fait la Force" in matters mechanical, quite as well as in national affairs.

Are the conditions which surround the American machinist more favourable than in other countries to lead him to take a lively interest in his work? Does not the American design and construct better machinery because he is himself a better workman or receives more aid from his men?

It is thought by many that such is the case in the United States, and while the writer would like to take up the why and wherefore of it, he will, at present, dwell only upon certain examples of special shop practice,— some call them "wrinkles," —devices for doing a certain thing either more quickly or more accurately, usually both. They are always deeply interesting to mechanical minds on account of the combination to be found in them of sharp and correct observation with great ingenuity; and they usually prove of service in unforeseen ways, leading to the development and invention of entirely novel construction. The abundance of these bits of clever contrivance in American machine shops goes very far to prove how closely Americans have studied the practical, the workman's, part in mechanical construction.

The trials of cutting off stock in a lathe are well known. In every well-appointed plant special cutting-off lathes or saws are found for the purpose. At the works of the Brown & Sharpe Manufacturing Company at Providence, R. I., a special tool block or holder is in use on their cutting-off machine, which seems almost ideal and is as simple as it is clever and efficient. The tool itself is a thin and very deep slab of steel. A portion of the tool is ground for use as the cutting-off part; on the top and bottom edge of the remainder, which is of uniform thickness throughout, a bevel is ground.

The tool rests in the holder against an upright surface, the lower bevel fitting in a corresponding recess. A clamp binds the tool most securely. A glance at the cut below will show the arrangement, by which are secured all the advantages of a thin cutting-off tool and of a very rigid holder.

The overhead countershaft was provided with what are known as Evans friction cones. In this device, Fig. 2, the pulley on the upper cone shaft is the driving pulley for the machine below. The upper cone is driven by the lower one through the belt ring which constitutes the contact surface between the cones. As this ring is shifted, the speed ratio changes. So far the well-known patent had been used; but in place of the customary belt-shifting attachment, a lead screw was fastened to the belt ring, as shown in the sketch.

The cross-feed screw of the cutting-off machine was connected directly by an upright shaft and universal joints to this lead screw, and as the tool advanced towards the centre, the countershaft, as well as the lathe, speed increased correspondingly.

The machine was busy, when the writer saw it, cutting off tool steel pieces for cutters. This is very severe duty; but the pieces were sliced off rapidly and easily, and the surfaces left by the tool were as perfect as could be desired.

The operation was automatic, excepting that the operator set the bar for the cut and ran back the cutting tool. One man could attend to three of these tools, with a total output exceeding that of a dozen lathes. Consequently, the cost of cutting-off is a mere trifle, per cutter. This company has a large trade in milling cutters of every description, sending them to every part of the world, even well-appointed shops in the United States finding it to their advantage to buy rather than to make them. This result has been achieved by a perfect mastery of every mechanical move in making the cutter, combined with the most enlightened theory. The cutting-off tool and its attachments, which are given as an example, are the first step, merely, in a series of operations, each as thoroughly mastered as this one.

When a lively, irresponsible boy speaks of chucking an object, he means

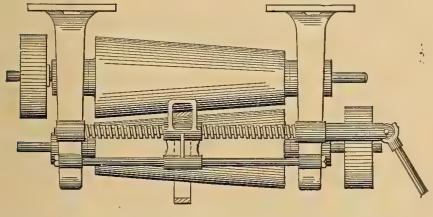


FIG. 2.—EVANS CONES WITH AUTOMATIC SPEED CHANGING DEVICE

throwing it away from him; but the Yankee uses the same word to express holding fast in the superlative sense. Chucking, with the latter, is to centre a piece of work in a lathe chuck, preparatory to boring it. It means, also, the actual operation of boring. A chucking lathe is a lathe especially for boring, and a chucking machine is a special boring machine. It was some trifle like this which led Talleyrand, who spent some little time in New England, to conclude that language was given to conceal thought.

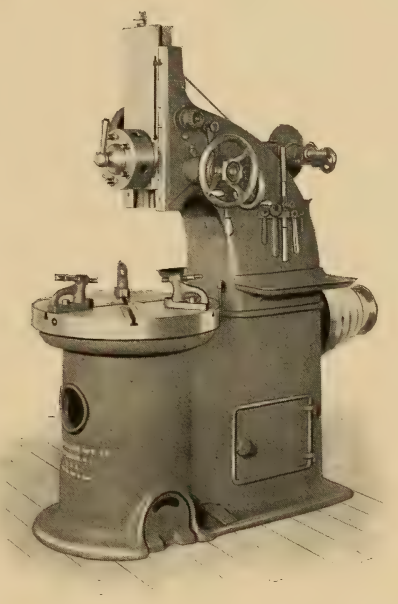


FIG. 3.—A RECENT FORM OF CHUCKING MACHINE WITH HORIZONTAL FACE PLATE. BUILT BY THE BROWN & SHARPE MFG. CO., PROVIDENCE, R. I., U. S. A.

Chucking is a very important feature in the machine construction of to-day, which requires that all holes should be uniform, standard and round. This could be done in the past by hand reaming, but only at great cost of time and labour.

The Yankee chucking lathe is a gap lathe with a monitor, or turret, head; and a very useful tool it is. But the most recent chucking machine, has a face-plate, turning in a horizontal plane, the turret head being vertical and the tools feeding down through the bore. Every one knows how much quicker a piece can be centred on a horizontal than on the usual lathe face plate. It is another and a more important gain that the chips fall away from the tool to the ground, instead of into

the cutting edges, as they do with the lathe class of machine. Moreover, the vertical chucking machine keeps its alignment.

The tools used are as interesting as the machine itself. The turret takes four or five tools. There is a very stout bar with a single pointed cutter to remove the scale. This is followed by a roughing tool, either a double-ended cutter inserted in the bar, or, a large twist drill. Afterwards comes a solid reamer. The final size is given by an adjustable blade reamer of very solid construction. Both the reamers are held loosely. On the shank is turned a semicircular ring which bears in the holder. This acts as a species of universal joint and lets the reamer "wobble" and follow the hole, imitating the action of hand reaming. The operation of boring by this machine is extremely rapid. One man attends to two machines, and the product is much nearer to perfection than would be thought possible.

This machine, like all tools of the most advanced school, is rigid and powerful in superabundance; and by it a short way has been developed to bore interchangeable taper holes, which is simplicity itself. Taper boring in the usual way presents many practical difficulties and is a tiresome operation. The modern way, when there are a number of taper holes to be finished, is to rough out the hole with a reamer, which has cutting edges like little steps, or saw teeth. This tool, being forced down into the bore and revolved, cuts the scale and roughs out the hole with a few revolutions of the spindle. The bore is then finished by one or two reamers of the usual construction.

Accurate holes, true to size, form the very ground for interchangeable work looking to large product and low cost. When this has been secured, the shafts can be turned and ground for these bores to either a free or a tight fit, the exact size in thousandths of an inch being easily ascertained and just as readily reproduced by the grinding machine. The old-time calipering, with frequent cut and try, and great waste of time, has passed away from progressive shops.

The broad principle underlying every metal-cutting operation is simply this, — support the piece to be operated upon so that it can withstand the tool pressure, and provide an unyielding cutting edge. The nearer you come to this ideal, the greater will be the results. Nowadays we have come to look upon all kinds of machine tools as of the same family. When correctly made, they will perform equally good work, and whether a piece should be operated upon in the drill, lathe or planer is frequently not a matter easily settled.

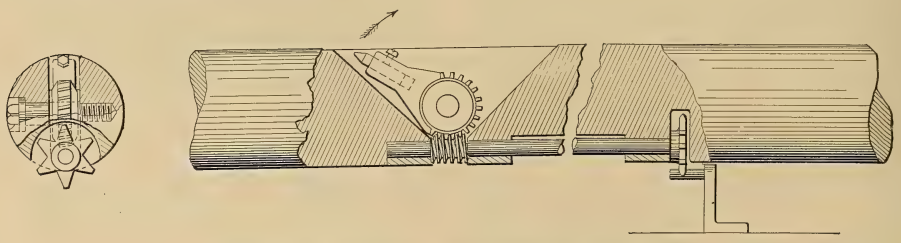


FIG. 4.—A BORING BAR FOR SPHERICAL SURFACES

For example, a manufacturer of large turret machines was in the habit of facing, in a boring and turning machine, the recess on the slide wherein the turret head rotates. The slide was very long, over two feet. This made him use a 50-inch machine to face a surface about 10 inches in diameter. Accordingly, he made two very strong heads with inserted teeth, to be fixed to a heavy drill press. One was for roughing, the other for finishing. Now, the work, which formerly no one would have thought it possible to do in anything but a lathe, is swept out and fin-

ished to perfection in a drill press. Of course, it took a modern drill to do it. The saving from this operation was twofold; it cut down the actual working time a little over one-half, and it left a

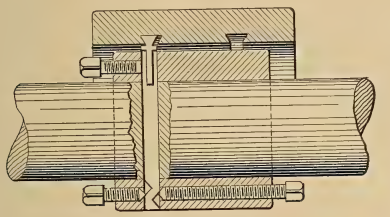


FIG. 5.—DOVE-TAIL CUTTER FOR BABBITT METAL BEARING

very expensive tool for work in its class, the drill press representing less than one-quarter the investment in the boring and turning machine.

The inventors of rotary engines have displayed marked liking for spherical surfaces in their designs. In a number of them will be found half-sphere cylinders and pistons. No one who can present clearly to his mind the definition of a sphere, and who realises, also, how near is the accuracy of machinery to mathematical exactness, would ever give serious consideration to such a construction. Within a few years a very large sum of money was put into a plant for manufacturing rotary engines of this type. While a true sphere is beyond us, at least to day, it is quite possible to turn an internal spherical surface good enough for some use. In some cases, it is very useful to have a self-adjusting box, held in a bearing of this shape. This bearing is easily made by the boring bar with inserted tool, shown in Fig. 4. The tool is pinned through the centre of the bar and is fastened to a little wormwheel. On turning the worm, the tool cuts the desired surfaces as the bar revolves.

Babbitted bearings have come into general use in late years. There are many ways to hold the babbitt, but a favourite method is to cut dove-tail recesses in the casting, so that the bearing metal, on casting, flows into the recesses and holds itself fast. These dove-tails can easily be cut in the milling machine if the piece be small; but when the casting is too large for the milling machine, they are best cut by the fixture shown in Fig. 5. The hole is first bored to the size. Then a bush is slipped over the bar. This bush carries a cutting tool with side edges turned to the same taper as the dove-tail. The tool is fed into the work by a set screw with a long taper point, fitted out of line with a corresponding taper hole in the shank of the tool. As the set screw is moved inwards, it presses out the point of the tool. The tool is withdrawn by another set-screw, so placed as to force the tool the other way when screwed inwards. When the cut is made to the desired depth, the boring bar is fed in both directions and the

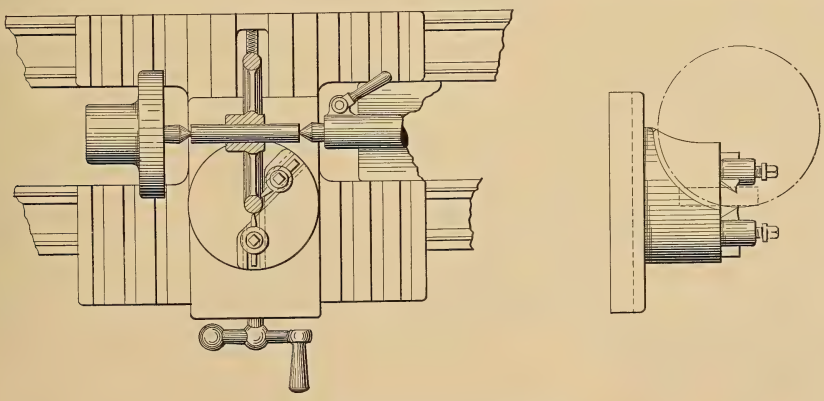


FIG. 6.—TURNING A HAND WHEEL RIM

tool cuts the angles with its side edges.

Devices for planing accurately have received a great deal of attention. The writer saw one, the other day,—a very simple fixture and of general application. Behind the work, on the planer, was a cast iron frame, representing the work in cross-section. On this were planed surfaces corresponding to the surfaces to be planed on the piece. The work was set according to the fixture, and all that the planer hand had to do was to set his cutting tools by the planed surfaces of his fixture. There was no measuring and the work was interchangeable.

An operation which takes some skill and practice is to turn the round rim of hand wheels. Various devices have been gotten up to aid the workman. There is one which does the work so automatically that a boy can attend to two machines and turn out better work than could formerly be done by the most skillful hand.

There is a compound rest on the lathe, built like a short column. On this are two tools, set about 100° apart, and so held that they point to the common centre around which the compound rest turns. In this axis, near the top of the column, is a hole to receive arbors. When it is desired to turn a hand wheel rim of, say, one inch diameter, an arbor of one inch is put into the hole and the tools are set to touch it. Were you, then, to rotate the compound rest, the tools would turn a circle of one inch diameter. The arbor is withdrawn, the hand wheel put in the lathe and the compound rest brought to the rim. By rotating the rest the rim is finished to a perfect circular segment in next to no time. Fig. 6 shows the arrangement. Handwheels and little fly-wheels enter very largely into the design of all kinds of machine tools, sewing machines, and, in fact, all automatic and semi-automatic machinery. The cost of turning them by this arrangement is nominal.

Further examples would probably tire the reader's attention. In selecting them the writer has endeavoured to find those which are of general application; with slight changes they may be used for other special operations.

We can see in them abundant evidence that we do not work mechanically. The conditions under which we work are such that minds of ability are found willing to give their attention to the study and development of machine building as a handicraft. They can be, and are, in close touch with their men, who, on their side, are encouraged to take an active interest in what they are doing.

It is said frequently that Europe will cease to buy American machines as soon as enough shall have been secured to serve as models. Undoubtedly this is true for so much of the American product as can be copied; but it does not hold for the work of the leading constructors in the United States.

This cannot be imitated, except by reproducing the system by which the machines were produced. No one can copy successfully an American locomotive, typewriter, or cash register, or certain types of boring and turning mills, milling machines or planers, because the designs of those machines represent the least part of the thought and study which they have cost. What has cost on those and like machines is the finding out the way to do the work of constructing them rapidly and well. As Kipling says, "This is another story."

FIGHTING THE ICE IN RIVER AND LAKE

By George E. Walsh

WHEN winter settles over the northern hemispheres of two continents, the ice which slowly forms and solidifies on lake, canal, and strait ties up the commerce on some of the most important water-ways of the world. Russia, Norway, Sweden, Holland, Canada, and the northern tier of States of North America are ice-bound from the beginning of December until the warm weather of spring thaws them out. By common consent canal shipping practically ends a month or more earlier than the first of the calendar winter month, making the season for canaling so short that a great amount of traffic must pass through each one to make it profitable.

The canals affected by King Ice, and closed up during the winter by his iron hand, represent some of the largest and most important water-ways of the world, and when Russia finishes her great canal from the Baltic to the Black Sea, —a total distance of 1080 miles,—another great artery of travel will come under his dominion. The greater part of this enormous canal will be navigable only seven months in the year, and as its estimated cost is put at about £20,000,000, it seems as if the season for

THE ICE BREAKER "STE. MARIE" ON THE GREAT AMERICAN LAKES. BUILT BY THE DETROIT DRY DOCK CO., DETROIT, MICH.

shipping is almost too brief to make the canal pay.

In Belgium there are twenty-nine canals in service to carry on the internal commerce of the country, all of which are practically closed in winter. Holland is honeycombed with canals and artificial rivers which simply furnish good skating ponds seven months out of the twelve. All of the other countries of Northern Europe are similarly situated, with innumerable canals and inland bodies of water closed to all shipping and commerce throughout the coldest of the winter months. In the northern part of the United States and Canada the tribute levied upon commerce by the ice king is even greater and more severely felt than in Europe. The great system of inland lakes becomes ice-bound early in the season and the rivers, straits, and canals that connect one with another, and open them up to the commerce of the ocean, are not navigable after the first of December.

As the great commerce of the American Northwest develops, the importance of having a clear water-way from the great lakes to the ocean at all seasons of the year will grow. The immense wheat fields of Manitoba are yearly increasing the grain supplies that roll in a golden stream through canals and by rail to the Atlantic seaboard, and Canada is making improvements in her vast canal system to facilitate this movement. The competition for the wheat-carrying trade between the canals and railroads becomes fiercer every year; but the latter have the advantage of being able to distribute their trade over twelve instead of only six to eight months in the year. During the season when the all-water route is open, the cost of carrying grain to the Atlantic seaboard is reduced to the lowest minimum, and the railroads have to meet this competition by similar reductions.

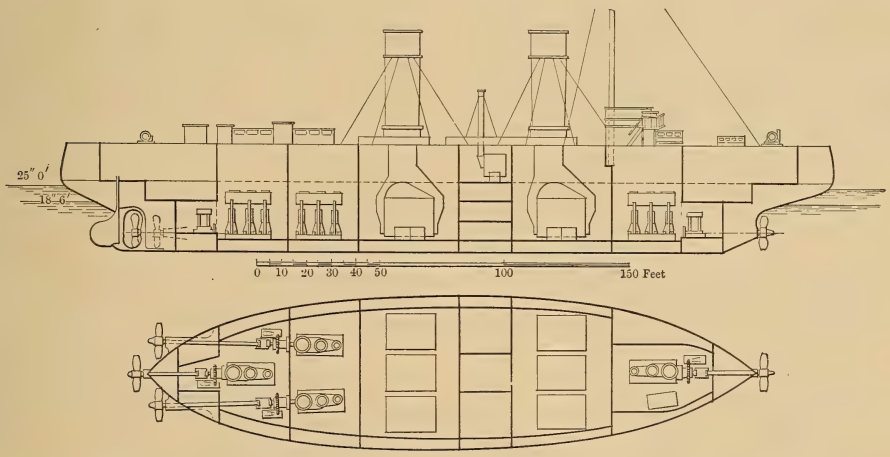
The enlargement of the St. Lawrence canals is going on to-day, and with the completion of these improvements vessels carrying 70,000 bushels of grain will be able to pass from Chicago and Duluth through the Welland Canal to Montreal without breaking bulk. Grain

THE ICE BREAKER "ERMACK," BUILT FOR THE RUSSIAN GOVERNMENT BY SIR WM. G. ARMSTRONG, WITHWORTH & CO., LTD., NEWCASTLE-ON-TYNE

will thus be carried from Chicago to the ship's side at Montreal as low as three cents per bushel. Another project is under consideration by British capitalists to construct a canal from the Georgian Bay to the Ottawa River, opening the shortest and most direct all-water route from Chicago to Montreal, and, hence, the Atlantic Ocean. If this canal be ever finished, it will be possible to carry grain during the open season to the seaboard for two cents per bushel.

It is believed that at an early date the grain exports from Manitoba and the northwest territories of Canada will exceed 100,000,000 bushels per annum, and properly this enormous quantity of wheat should go through the great lakes and canals to the Atlantic seaboard, thereby saving to the consumer several cents per bushel. Before the Erie Canal was built, the cost of carrying grain to the seaboard was several times as high as it is to-day. The reduction has been going on steadily, and not easily overcome to-day during very cold winters. Whether it will ever be possible to keep the all-water route from the great lakes to the ocean open all through the year is a question that the future must decide, but the important achievements in battling with the power of the ice already accomplished have attracted more than ordinary attention.

It was when the pioneer railroad across the peninsulas of Michigan, in the United States, was first completed that efforts were made to break the dominion of the ice. The straits of Mackinac, which separate the two peninsulas, are nine miles wide, and across them the great ferries of the Duluth, South Shore and Atlantic Railway travel. The straits are pleasant waters in summer time, and tourists passing across them in the large, commodious ferryboats would never think of the terror they might inspire in winter. The cold grows so intense here that several feet of ice form on the surface,



ELEVATION AND PLAN OF THE RUSSIAN ICE-BREAKING STEAMER "ERMACK."

it would remain at a low fixed rate all the year if the water route did not freeze up periodically.

It was some years ago that determined efforts were first made to break the power of the ice in the Northwest, especially on the lakes and straits which connect important lines of travel. The problem was a formidable one, and it is increasing to five and six feet in severe winters.

The question of keeping the straits open so that the ferryboats could continue their traffic was taken up by the railroads, and the ice-crushing boat *Algoma* was built. She was the result of careful study and the application of principles never before employed in

marine architecture. No similar boat was ever before launched. Although she was a failure so far as accomplishing the work cut out for her was concerned, the principles of her construction were practically correct, and they have since been adopted by most of the builders of all the subsequent ice-crushing vessels.

The *Algoma* was built by the Detroit Dry Dock Company, of Detroit, Mich., and was of 500 tons burden; but though so small, she was equipped with engines that developed 2000 horse-power. These powerful engines for so small a boat were intended to drive her against the ice with force enough to crush it. At the time of her construction probably no craft of her size had been fitted up with engines of equal power, and she was a marine wonder in this as well as in other respects. Another point of departure from the accepted principles of boat-building was that her draught was much greater aft than forward, and that her bottom was rounded. She was supposed to charge against the ice with all the force of her powerful engines, and by virtue of her peculiar construction she was to slide up and over the ice, thus crushing it by her weight. The old method of breaking the ice had been to propel the boat against it with the sharp prow for a battering-ram, and when her headway was stopped to withdraw and deliver another blow. Where the ice was comparatively thin, this battering-ram method answered very well, but it had little effect against very thick ice.

Various schemes for ice-breaking have been suggested and tried, from the simple method of battering it with a heavy prow to crushing it with dynamite; but none of them have proved so serviceable as that embodied in the *Algoma*. But, after all, this boat was too light in weight to perform her work adequately. She was caught in the ice many times, and had to be freed with ice-saws and dynamite. One winter she spent two weeks in this condition. When she dashed against the ice she would break a passage way well enough for a few hundred feet, but as she proceeded the ice accumulated under her until it would support a weight several times greater than that represented by the vessel.

Ten years ago, after this first ice-crushing boat had demonstrated the success of the principles her builders had in mind, she was superseded by another of more formidable dimensions. The *St. Ignace* was more than twice the size of her little predecessor. She was 235 feet long, 52 feet beam, and of 1200 tons burden. She was built with the sloping prow that distinguished the *Algoma*, but she had a screw-wheel under the forward part of the hull, as well as at the stern. The object of this peculiar construction was to force the boat's prow upon the ice to crush it, and the forward screw would render this task easier by sucking the water from under the ice. When in operation, charging the ice, the steamer looked as if trying to climb up on the surface, but was constantly frustrated in the attempt. The forward screw would suck the water from under the ice so that it would bend down by its own weight, thus making it easier for the prow to slide over it and complete the work. The forward screw also helped to clear a channel for the boat by tossing the broken pieces of ice to either side. Thus, the main aft-screw was relieved of all work other than that of giving speed to the steamer.

For five years the *St. Ignace* battled with the ice in the straits of Mackinac, keeping the channel open most of the time, but occasionally succumbing to the inevitable. The ice would pile up in such windrows that often she would be unable to struggle through it. But her improvement over the old *Algoma* was so marked that it was decided to construct still larger ice-crushing boats on the same plan.

Thus it was that the present fleet of great, powerful ice-crushing boats of the American Northwest came into existence. To-day they represent a fleet of unique craft. They have become of more than national importance and the Russian Government has had naval officers on the scene to witness some of

THE ICE-BREAKING STEAMER "NADESHNY," BUILT FOR THE RUSSIAN GOVERNMENT, BY MESSRS. BURMEISTER & WAIN, COPENHAGEN

their trials. The last visitor was Rear-Admiral Makaroff, who spent several days on the big ice-crushers last winter, and, as the result of his visit, the ice-crusher *Nadeshny* has been built at Copenhagen, and another of similar type has been turned out by the Armstrongs in England. Northern Europe will soon make a systematic effort to unlock the grip of ice on the lakes, canals, and bays near the principal cities.

The ice-crusher *Sainte Marie* succeeded the *St. Ignace* about five years ago on the straits of Mackinac in the United States. She has a keel length of 270 feet, and a total measurement over all of 305 feet, with a width of 53 feet. Her engines are of 4500 horse-power. She is provided with a stern and forward screw, like her earlier, but smaller type.

The construction and equipment of this ice-crushing boat is superb, and she is almost as rigid and firm as a modern battleship. The pressure on the hull is so great at times that an ordinary steamer would have its sides crushed in like an egg-shell. The builders had to consider all this when making the plans. The hull below the water-line is built of solid timbers, and braced with massive planks of white oak. An outside planking, 6 inches thick, is put on, and this is sheathed with ¼-inch steel.

But the vessel was built for something besides crushing ice. She is in the service of the railroad company to carry freight across the straits, summer and winter. So great is her power that she can carry eighteen loaded freight cars on her deck, and go crashing through 24 inches of ice at a speed of about eight miles an hour. Equipped with a powerful searchlight, she can make her trip across the straits during the darkest and coldest nights of the winter.

The fight to keep the straits open through the winter begins early in the season. The *Sainte Marie* breaks a channel first for the other boats to follow, and then, as she makes her trips back and forth, the work is not difficult until an intensely cold wave comes. Then the cakes of ice freeze up solid in

the wake of the ice-crusher within a few minutes after they have been broken. With the thermometer registering forty degrees below zero, the normal thickness of the ice steadily advances from two or three feet to five and even six. This enormous thickness, however, can be overcome by the *Sainte Marie;* but there is a peculiar action of the ice that sometimes makes great trouble. It is the tendency of the broken ice to freeze up under the water, piling one thickness upon another, forming what are called windrows. As the ice-crushing boat goes back and forth on the same trail, the ice extends down deeper and deeper until a windrow measures from twenty to thirty feet in depth. The *Sainte Marie* has travelled successfully through windrow ice of this average thickness; but when it begins to assume this formidable opposition to her progress she generally tries to break through another path.

This windrow ice has been piled up on either side of the steamer to a height of twenty or more feet, and below the water it has been known to extend from 100 to 150 feet. This occurs only during exceedingly severe winters. It happened two winters ago when, for the first time, the *Sainte Marie* was caught. She was hemmed in so with mountains of ice that she could not move. But after she was sawed out so that her screws could be used again, she freed herself from her prison and renewed the battle.

The *Sainte Marie*, while representing the best of the modern fleet of ice-crushing boats, is not the largest in existence. Since her day larger and more powerful ice-crushers have been built in the American Northwest, but they are modelled on the same lines. These recently-built vessels have 7000 horse-power each, and are capable of working their way through almost any ice-barrier likely to oppose them.

The ice-crusher *Nadeshny*, built at Copenhagen, is smaller than the members of the fleet in the American Northwest, but she is a fine specimen of her class. She is 280 feet long and 43 feet beam, and has a horse-power equipment of 3600. She was built for the Russian Government to break the ice in the harbour of Vladivostock. The crusher built in England is also for the Russian Government, but she will have a displacement of 8000 tons, and an indicated horse-power of 3000. This will make her much less powerful than the *Sainte Marie*, but probably effective enough for the duty required of her. She is intended for river work. It will be her mission to keep the channel open on the Neva River between St. Petersburg and the Baltic Sea. As this is a distance of 200 miles, she will have ample opportunity to test her powers in all kinds of seasons and circumstances. But, like the *Nadeshny*, she is only the forerunner of a fleet of heavier ice-crushers if she lives up to her builders' expectations.

All the new ice-crushers are sheathed with steel. Those used in the American Northwest are designed to carry their freight on deck in the shape of loaded freight-cars, and the resulting top-heaviness has to be overcome by water-ballast below decks. The *Sainte Marie*, for instance, has huge cylindrical steel tanks low down in the hull. The earlier ice-crushers were provided with no such ballast tanks, and they wobbled and staggered about in such a fashion that the cargo was sometimes dangerously shifted.

The *Nadeshny* has been provided with water-ballast steel tanks also; but they are arranged more for the purpose of changing the draught of the boat than for overcoming any deck load. Her ordinary draught will be 13 feet forward, and 18 feet aft. But when she encounters unusually thick ice upon which she must climb to crush it, the draught can be changed so that, forward, it will be but 9 feet, and aft, 22 feet.

The modern ice-crushing boats of both continents will play an important part in the history of commerce of the future, especially in those countries where the ice barrier is an enemy difficult to combat. In Europe they may even figure in a political sense, for Russia is extending her dominion and power in the East by freeing herself from the

chains of ice that have so long bound her commerce throughout half the year. Not less important may this prove to her power in the East than the construction of her great canal and Trans-Siberian railroad.

ELECTRIC LIGHTING OF RAILWAY TRAINS IN GREAT BRITAIN

By H. Scholey

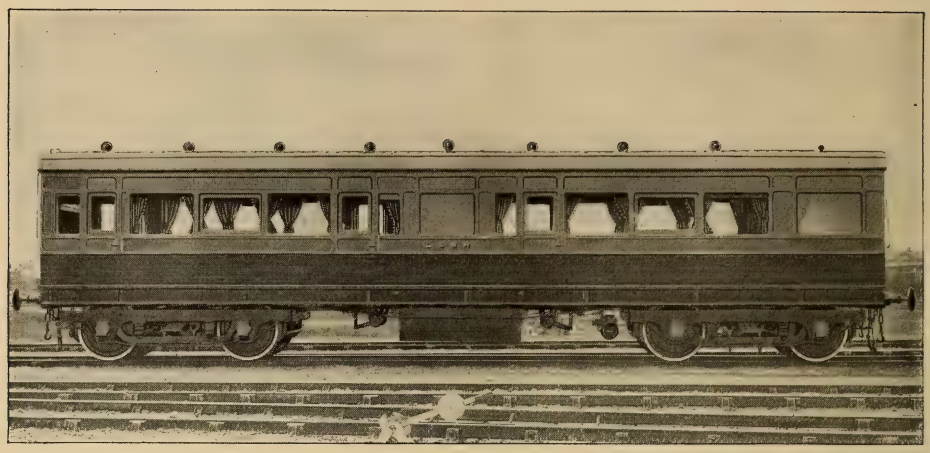
A LONDON AND NORTH WESTERN RAILWAY TRAIN LIGHTED ELECTRICALLY BY THE STONE SYSTEM

WITH all the luxury of the modern railway train, it is a little curious that the lighting of carriages should not have made greater progress, and that railway companies have been slow to adopt the improvements that have been effected in illuminating agents.

While it is true that, on the more enlightened railway systems the early oil lamp has been partially, if not entirely, superseded, there is more than one railway company having an important terminus in London which still relies on this inefficient, and, moreover, expensive, means of lighting. The introduction of gas lighting on trains promised well, and though on many lines a fair illumination is provided, the general experience,—and this especially applies to long-distance journeys,—is that gas, as far as effective illumination is concerned, has not proved to be very much better than oil.

Although electricity, almost from the outset, appeared to offer the best means of lighting trains, it has, until recently, been used to so slight an extent as to suggest that almost insuperable difficulties stood in the way of its adoption. It is interesting to dwell for a moment on the early experiments in the electric lighting of railway carriages. We shall then see why there were distinct limitations to its use.

It must be admitted to the credit of



A LONDON AND SOUTH WESTERN COMPANY SALOON CARRIAGE FITTED WITH THE STONE SYSTEM

the railway companies that they have generally exhibited a keen desire to adopt electricity, and as far back as 1880 the Lancashire and Yorkshire and the Great Eastern made unsuccessful experiments. A certain measure of success was achieved on the London, Brighton and South Coast Railway in 1881, when a Pullman car was fitted with accumulators. The cells were charged every night from the stationary plant at the terminus, and it may be assumed that the results were, to some extent, satisfactory, for there was a gradual extension of the system to complete trains.

Experiments on a still larger scale were carried out on the Midland and the Great Northern, and it is important to refer to the experience of the former company because the difficulties met with were just those that stood in the way of other companies which tried to adopt electric lighting. The method originally employed by the Midland Railway Company was to place, in the guards' van, a dynamo which was driven from the axle. In each coach of the train were placed a set of accumulators which came into action at stopping places and when the train slowed down. But it was soon found that trouble arose from the interposition of unfitted stock into a train, and this, combined with the comparative ease with which a gas-lighted coach could be dealt with, eventually led to electric lighting being abandoned.

Though this is a record of distinct failure, it was felt by the officials of the Midland Company that it was only temporary, and quite recently the electrical engineer of this line declared that "train lighting by electricity is destined to come into general use, and were it possible to dispense with the use of accumulator batteries to-morrow, or to produce an accumulator battery capable of withstanding the rough treatment railway traveling imposes upon it, there is no doubt that the progress of railway train lighting by electricity would be greatly accelerated."

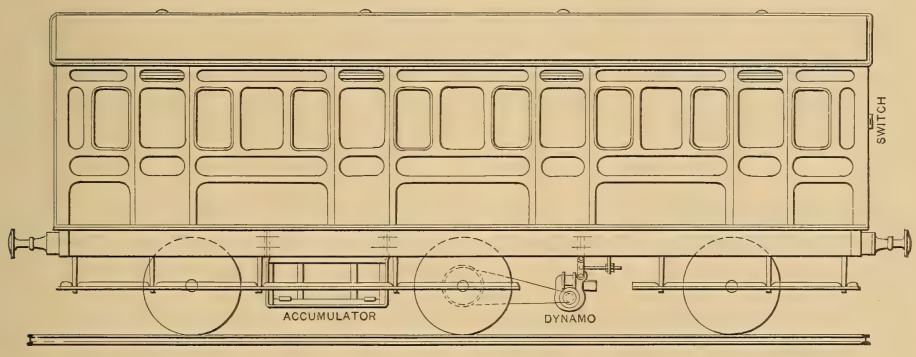
But an investigation into the present position of train lighting reveals a most interesting state of things. It is not more than three years ago when the Midland Company abandoned its experiments. Yet what do we find to-day? The change is a complete and startling one. Among the smallest railway companies in the country is the London, Tilbury and Southend Railway; yet on this system alone there are practically 300 coaches fitted with electric lighting. The whole of the stock on the Barry Railway and on the Furness Railway are equipped in a like manner, and the South Eastern Railway, which, in the matter of train improvements, has hitherto been somewhat sluggish, has adopted electric

lighting on nearly 350 coaches. The London and South Western Railway has also equipped 170 coaches, and it is understood that both they and the South Eastern Railway have decided to fit the whole of their new rolling stock with the system. The London, Brighton and South Coast Railway have also came to the same decision with regard to their new stock, including 200 coaches at present on order.

Nor are the Northern railway systems behindhand. In addition to further experiments on the Midland Railway, the London and North Western, after sundry trials, resolved, last summer, to equip 60 large bogie coaches, and since then have decided to fit up 16 trains with electric lighting. These instances, taken in conjunction with the fact that practically all the other British railway companies are making experiments on the same lines, suggest that some noteworthy development has taken place in the method of electrically lighting trains.

The most remarkable feature in the revival of electricity for train lighting is that it has been mainly caused by one system, the invention of Mr. A. B. Gill. It is commonly known as Stone's method of lighting, having been patented and introduced by the London firm of engineers, Messrs. J. Stone & Co. So widely has it appealed to railway men that already it is in use on upwards of one hundred railways, including several American railways. The details of a method which has practically created a revolution in the illumination of trains is obviously of interest. In its essential feature it consists of a dynamo placed underneath the carriage, being driven from the axle. To merely drive a dynamo from the axle of the carriage is one of the oldest arrangements in train lighting. It was done on the Midland, on the Brighton and South Coast and in Australia many years ago. But it is not difficult to conjure up the difficulties that such a method must contend against. All systems that embrace driving from the axle must provide some means of meeting the variation in speed of the train. It is in the manner of solving that problem which gives to the various systems their distinctive characteristics.

The simplest method that would occur to an electrician would be to utilise



ELEVATION OF CARRIAGE SHOWING METHOD OF HANGING AND CONNECTING THE DYNAMO

the excess current generated by increased speed, to partially demagnetise the field magnets, thus keeping the output of the dynamo within certain definite limits. This formed the basis of more than one method, but they each necessitated delicate means of governing, and this was partially responsible for their comparative failure.

In the Stone system there is a complete departure from this method of compensating for speed variation. The dynamo is suspended from the under frame of the carriage in such a position that its driving pulley is practically on a level with the axle pulley, from which

it is driven by a belt. By such means it is claimed that none of the vibration or vertical motion of the axle is transmitted to the dynamo. The substantial difference between this and former systems is that, no matter how great may be the variation of speed, the dynamo always runs at a fixed speed, and consequently produces practically a constant amount of electricity, and this is achieved in a comparatively simple manner.

The dynamo is suspended from the carriage by one corner and is held by means of an adjustable link in such a manner that it is free to swing. When connected by means of the belt to the axle pulley, the link may be so adjusted that the driving belt draws the dynamo out of its natural position. This adjustment is regulated to give a definite tension on the belt sufficent to absorb power equivalent to the amount of electricity required. In other words, it is possible by means of the adjusting screw attached to the suspending link to set the machine to supply a certain definite number of lights. In endeavouring to seek its natural position the dynamo exerts a pull on the belt. As long as the axle pulley runs within certain limits its pull on the belt is no greater than that of the dynamo; when, however, the train increases its speed the axle exercises a greater pull on the belt, and this has the effect of drawing the dynamo towards the driving pulley, with the result that the belt slips while the armature continues to revolve at its normal speed. Increased speed means more slip, and in that we have the secret of this system of train lighting.

The truth of this could be demonstrated in no more certain fashion than by the following table, which is based on experiments made under the supervision of Professor Slaby, director of the Royal Technical College of Berlin, and Professors Hagen and Neesen, of the German Patent Office:—

Speed of pulley on axle of motor (representing axle of railway carriage).	Equivalent speed of train in miles per hour (approximate).	Speed of dynamo Revolutions per minute.	Equivalent speed of dynamo if no slip were to take place.	Output of dynamo. Ampères.	Remarks.
Revs. per min.					
100	12	500	500	0	
138	16	690	690	2	The predetermined limit for speed of dynamo in these tests was 915 revs. per min. producing 20 amps. of current, which it will be noted was not exceeded, although the speed of pulley on axle of motor (representing speed of train) varied from an equivalent of 24 miles per hour when this limit was first reached, to 72 miles per hour.
150	18	750	750	6	
168	20	840	840	14	
175	21	870	875	16	
185	22	885	925	17	
195	23	900	975	18½	
205	24	915	1025	20	
225	27	915	1125	20	
250	30	915	1250	20	
275	33	915	1375	20	
300	36	915	1500	20	
325	39	915	1625	20	
350	42	915	1750	20	
375	45	915	1875	20	
400	48	915	2000	20	
450	54	915	2250	20	
500	60	915	2500	20	
600	72	915	3000	20	

The important fact revealed by this table is that the dynamo was set to achieve its predetermined output when the train was traveling at 24 miles an hour, and nothing could illustrate in more striking fashion the negative effect of increased speed on the armature.

It is hardly necessary to point out that all systems of train lighting which depend primarily upon the running of the train must be also furnished with a means of continuing the light when the train is at rest. It is customary, therefore, to provide a storage battery, and the system here specially considered is, similarily, not independent of the aid of accumulators. Originally a single battery was used in connection with the dynamo, but later practice somewhat modified this arrangement, and it is now usual to employ two batteries of accumulators, which insure that the light is always burning when required; moreover, such a dual arrangement per-

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mits of one battery being charged by the dynamo while the other is providing light.

There is nothing especially notable in the electrical details of the dynamos. In order to meet the very special conditions of usage, it is of strong construction, and the armature and running parts are suitably protected by weather-proof cases. It is of the ordinary two-pole type, the armature being usually Gramme-wound and carried on a shaft which is extended for the pulley. The automatic devices constitute the most important feature of the apparatus, the method of switching in and out being highly ingenious. On the armature shaft, on the brush side of the machine, there is a form of spider, carrying on each of its four limbs a contact; at the extreme end of the shaft is a centrifugal governor the action of which is easily explained.

When the train is at rest, or not running at the predetermined speed at which the dynamo operates, the battery is automatically put into circuit with the lamps, but as soon as the train has reached a certain speed the governor flies open and thrusts the rocking contact maker forward until it is forced into the contacts, which, through a resistance, connect the dynamo to the lighting circuits. This operation also reverses the two batteries, charging one and putting the one already charged in parallel with the lamps, thus keeping the voltage always constant.

It has been no easy matter to arrive at a form of storage battery which would withstand the undoubtedly trying conditions of railway work; indeed, it is the difficulty of securing a suitable form of cell that has, in the opinion of some authorities, stood in the way of a greater extension of electricity for train lighting. In conjunction with the present system, however, an accumulator having what is practically a Planté positive has proved to be most effective.

The automatic means of lubricating the bearings of the dynamo are decidedly novel. Attached to one of the pole pieces is an oil reservoir capable of holding sufficient oil for five or six weeks. Two siphon tubes are fixed inside, each carrying a small valve connected to a hinged piece of iron. If the dynamo were not working the hinged piece of iron would keep the valve closed and this would permit oil to siphon over and accumulate in the tube. Upon the field magnets being excited by the running of the train the hinged piece of iron would be attracted upwards and the valves opened. This would enable the accumulated oil to flow to the bearings, and while the train was running the lubrication would be accomplished by the oil slowly siphoning down the tubes.

It should be mentioned, perhaps, that the lighting of the carriages is usually effected by two circuits, there being a lamp on each. By this means it is possible to operate only half the lights, this being effected by a hand lever placed outside the carriage.

No matter how efficient a system is, in order to achieve permanent success it must exhibit some reasonableness in first cost, and must, moreover, call for no lavish expenditure in maintenance. It is clear that when once the plant is provided, the cost of generating the electricity is simply that for extra coal necessitated in driving the dynamos. But this is so insignificant as to be quite imperceptible; indeed, a series of tests made on several of the large railways failed to discover any increased consumption of coal.

Under laboratory conditions Prof. Capper found that the power absorbed in generating the necessary amount of current for ordinary railway coaches, when running at normal speeds, was 0.6 horse-power, while at express speeds the power absorbed did not exceed 1.1 horse-power. The above, says Prof. Capper, "is equivalent to an extra consumption of fuel, both at normal and express speeds of ½ pound per train mile, allowing ten coaches to a train, or one-twentieth of a pound per coach per mile."

Compared with other systems of train lighting, the electrical method starts with the advantage of obtaining the necessary energy at low cost. It is

true that the initial cost of apparatus would be heavier than would be necessary with an oil or gas system. For instance, if it were desired to equip 400 coaches with the electrical apparatus here considered, the initial outlay would be probably £26,000, whereas to supply gas plant and all the fittings on coaches would cost only something over £16,000.

The annual charges, however, tell overwhelmingly in favour of the electric system, for in the case just quoted they would be only, whilst giving double the light, £2690, including interest on capital, depreciation, etc., against £3789 for oil gas.

To summarise the position in another way, the cost of the electric system, including all expenses, would work out at 0.147d. per hour for a 16 candle-power lamp, while the oil gas would probably cost 0.209d. for an 8 candle-power lamp.

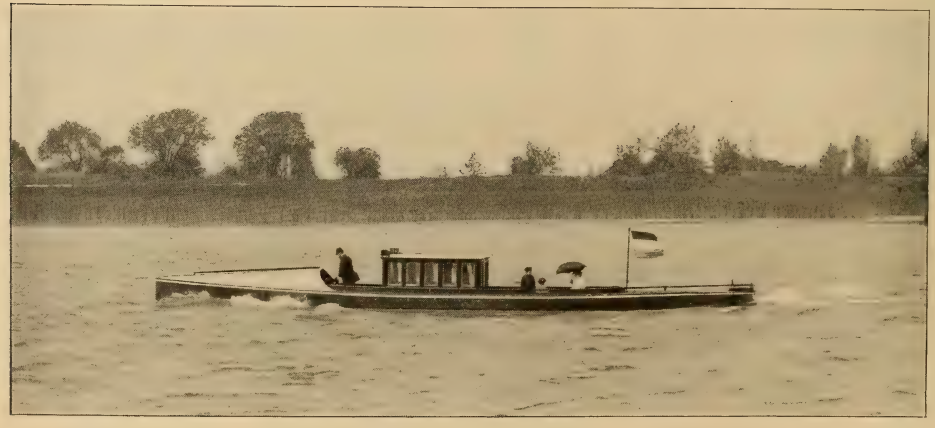
ELECTRIC YACHTS IN HOLLAND

By W. de Gelder

THE many natural and artificial waterways of Holland form a very important factor in the Dutch way of living, and a foreigner is always curiously impressed with the fact that many of the people who live in country houses, have, instead of carriages and horses, a launch or small yacht in their boathouse.

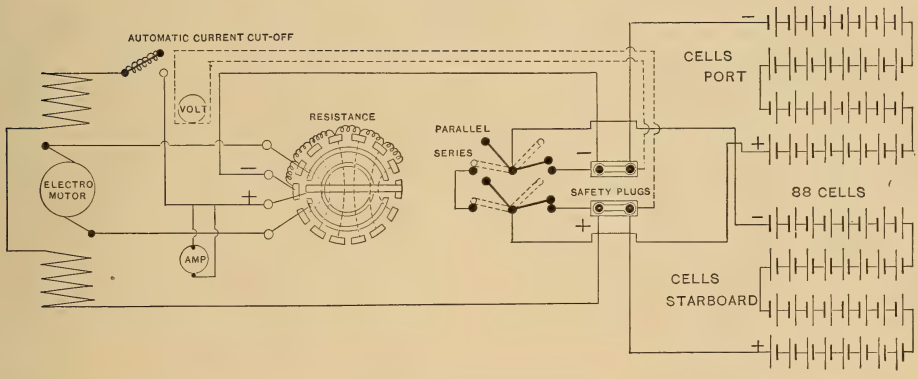
A steamboat of small size, however, has many inconveniences, and it was natural enough, therefore, that when the various types of oil engines came into use, they at once met with much favour in Holland, even though they were by no means ideal motors. But they had the advantage over steam engines that they did not take up so much room in a boat, and were cleaner, as no coal was used. They also dispensed with the services of an engineer; anybody could start the engine, and, when once started, it could be left to itself. An oil engine launch, moreover, could be made ready for use at a few minutes' notice.

Electrically-driven boats, however, had meanwhile reached a degree of

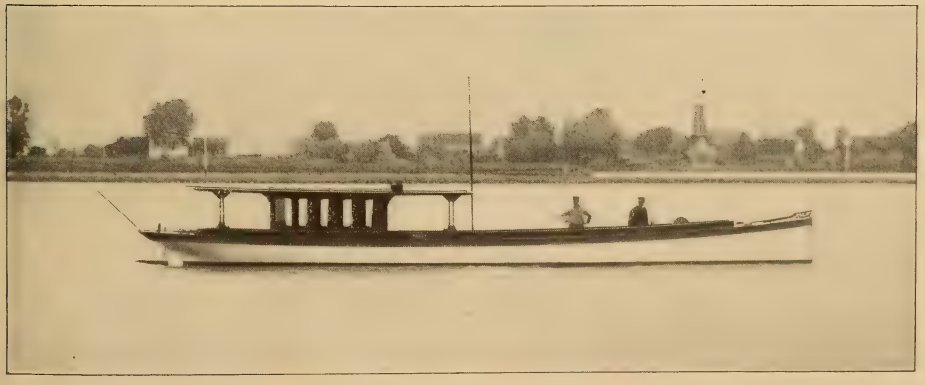


A LAUNCH FOR SHORT TRIPS

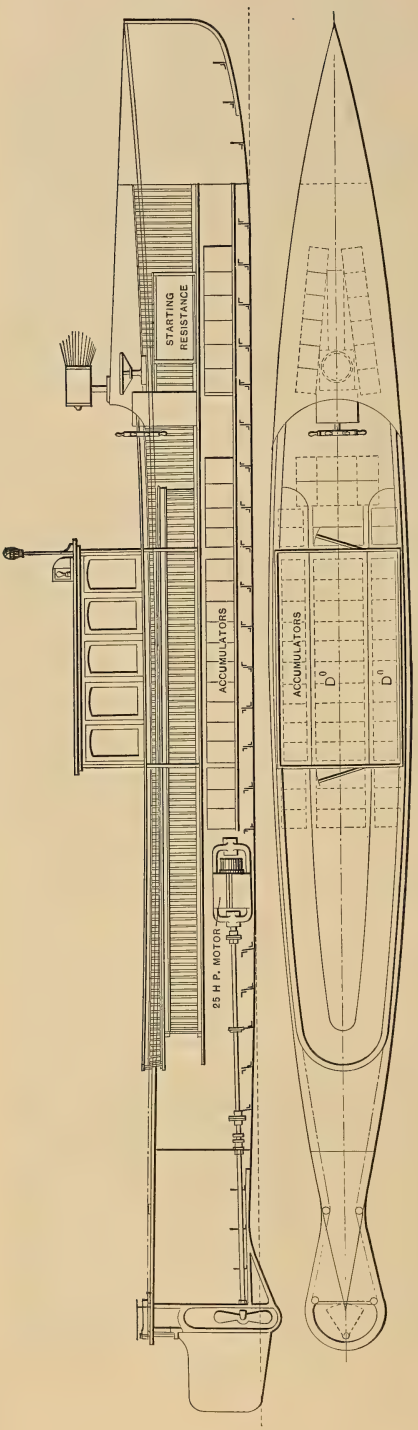
GOOD FOR GENERAL SERVICE



WIRING DIAGRAM FOR A YACHT



A LARGER SIZE



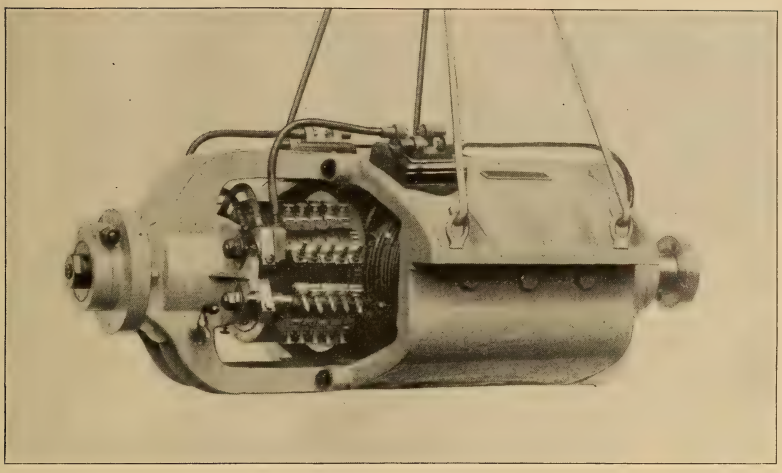
PLAN AND ELEVATION OF A TYPICAL ELECTRIC YACHT

perfection which promised to make their use more general. One great difficulty in the beginning was the question how to recharge the storage batteries; but with the growth of electric lighting everywhere, this has practically disappeared, and the chief disadvantage now is simply that of cost. The price of an electric yacht is considerably higher than that of a steam yacht, as the electric installation, especially the battery, is much dearer than a steam engine, with boiler. Cheap batteries may be had, perhaps; but a cheap battery would mean low efficiency and a lot of trouble in maintenance, so that, in the end, it would be the dearest.

A first-class battery specially made for its purpose, so that the rolling and pitching of the boat will cause no trouble, contained in strong boxes of ebonite or similar material,—a battery, moreover, that will allow a quick discharge,—should always be adopted. Such a battery will last a good while without looking after, requiring only periodic filling with acid.

The weight of the battery is an important point. As a rule, storage batteries have not yet attained that grade of perfection that may be expected, and this is the reason why, in one respect, at least, the steam engine has an advantage for boat propulsion. Generally, when the coal bunkers are well filled a steam launch has a greater "steam radius" than an electric launch. But this may be said to be the only advantage worth considering. A boat that has to do all kinds of rough work,—all-around work,—may vibrate, spread heat, be dirty and greasy, and noisy; but on a pleasure boat these features are collectively and individually objectionable. With an electric yacht all of them are avoided.

First of all, the motor and battery take up practically no useful room, as they are stowed away under the floor and the seats, and other available waste spaces. Moreover, they require very little attention, and may be entrusted to unskilled hands. When under way, they may be left quite to themselves. By turning a handle the



A 25-H.P. BOAT MOTOR

man at the helm stops, slows up, or reverses the motor at will. With the battery low down under the floor the stability of the boat is well secured.

The boat is always ready for business. Turning a handle is all that is necessary to start her. The loading of the battery, it is true, takes some time, —more than is required to fill the coal bunkers of a steam launch. But this always can be done without special inconvenience when the boat is not used.

A number of representative types of electric yachts as used in Holland are shown in the several illustrations accompanying this article. The boats shown all were built by Messrs. L. Smit & Zoon, of Kinderdyk, near Rotterdam. They all have neat little cabins; the joiner work is of teak; and the cabins are fitted up luxuriously. They are heated and lighted electrically, and the larger ones also are provided with electric search-lights.

ROLLING MILL FLY-WHEELS

By John Fritz

WITH the special interest attached to fly-wheel accidents that has been manifested within the past year the writer was requested, some time ago, to present his experience with rollingrmill fly-wheels in a paper for the Ameican Society of Mechanical Engineers, and this has been reproduced practically in full in the following pages.

In the early days of rolling mills, as it was there explained, the machinery was of the crudest character. The men who built and looked after it were called millwrights, or forge carpenters, and wood was consequently used in its construction to as great an extent as was possible. All of the earlier fly-wheels had wooden arms, at least so far as the writer knows, and Fig. 1 shows the general way of fitting them in. They were made of hard wood, locust or white oak preferred, and about six to eight inches in thickness, width as per illustration.

The wheel segments were in halves, and

secured together with gibs and keys. Having no machine tools when these wheels were built, they were put together practically as the castings came from the foundry, with the lumps and swells chipped off with a two-handed chisel and sledge, which naturally caused a weak wheel. They were made of cold blast charcoal iron, which was greatly in their favour, and no doubt this fact prevented many accidents.

In the course of time the millwright and carpenter were displaced by the machinist, and with the introduction of machine tools, especially the planer, the wheels were better fitted up, but not much safer in consequence of the use of iron, made from mineral coal, in place of charcoal.

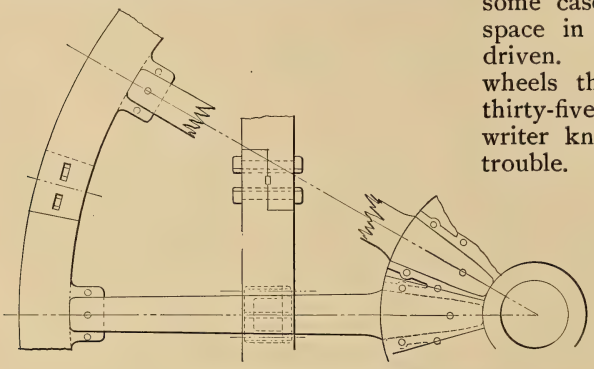


FIG. 1.—A FLY-WHEEL WITH WOODEN ARMS

The machinist now became the mechanical engineer, and wood not being his forte, he made the fly-wheel all of cast iron, as shown in Fig. 2. The centre, arms, and segments were cast separately, and had the ends of the segments been well fitted together, the wheel would have given no trouble. The slots for the tees were, unfortunately, too close to the end of the segment; the result was that they pulled the end of the casting off, and grooves had to be chipped across the face of the wheel, and heavy links put around them, as shown in Fig. 2, which made a good wheel out of it. This was done in 1854, and the wheel is probably yet in use, but never ran at high speed.

Not considering these wheels safe, the writer was in constant fear of their going to pieces. The old mode of making wheels was, therefore, entirely abandoned, and the plan was adopted of casting the centre and arms together, and the rim in one piece, with lugs on the inside of the rim, as shown in Fig. 3. On the ends of the arms were pads to correspond with the lugs on the rim. When the arms were put in the rim, there was a space of about one-quarter of an inch, in which oakum was driven tightly, which kept the arms in place. This made an excellent wheel, and in some cases wood was used to fill the space in which thin steel keys were driven. There are several of these wheels that have been in use over thirty-five years, and, so far as the writer knows, never have given any trouble. The wheels were 20 feet in diameter, with rims about 12 inches square.

With the introduction of steel for rails and structural material, it became necessary to increase the diameter of rolls. This change necessitated heavier wheels, and larger in diameter, which made it impracticable to use solid rimmed wheels; consequently, some plan that was portable had to be adopted. After much thought the plan represented by Fig. 4 was concluded the best and safest, and there are now a number of wheels of this type in use, varying in diameter from 20 to 30 feet. The writer does not know that any one of them ever has given a particle of trouble in any way, and there are a number of wheels, as per Fig. 6, that have been in use for twenty-five years, some which have, and are daily liable to encounter, the most severe strains that it is possible for a fly-wheel to be subjected to, and are to day apparently as safe as the day they were started.

It has been said that fly-wheels go to pieces in consequence of the irregular work, and engines driving dynamos for power purposes have been included in this class; but the strain on a fly-wheel driving a dynamo cannot be compared with that of a rolling mill. In the

former the work occasionally varies from nil to full power, while that of an engine driving a rail mill changes from nil to practically full power while rolling a single rail twelve times, which requires about one minute.

Let us for a moment think of a fly-wheel 26 feet in diameter, 16-inch rim, making from 70 to 80 revolutions per minute, rolling a steel bloom into a rail! When about one half done, say, about 16 feet in length, instead of the piece going straight out, through the rolls on the guides, as intended, it sometimes wedges in the groove, and in less than a second of time it has completely encircled the roll, and forms what in rolling-mill phrase is called a collar, and continues to wind around the roll until something must happen, either the breaking of a roll, a spindle, or coupling, or the engine must be brought to a standstill in an almost incredibly short space of time. The torsion on the spindles and couplings is so great that it causes the wheel to rebound. To calculate the strain to which the wheel is subjected under these conditions will require some one better posted in mathematics than the writer.

Having alluded to the fact that the introduction of steel in various forms required larger rolls, heavier wheels, and larger in diameter, which made it impracticable to use a solid rimmed wheel, led to the adoption of the plan of wheel shown in Fig. 4. The illustration makes it so plain that it wants but little explanation. The segment is cast hollow, and also the arms, which are made at the ends to compare in thickness to the segment, so as to relieve them of strains which might occur if the segments were cast solid. The holes in the segments are small at the ends, so as to make up for the metal taken out for the tees. The links, or tees, are different lengths, so that the strain on the segments will not come all at one place, and by using oil-tempered steel in the links, or double tees, the rim will be practically as strong at the joints as it is elsewhere.

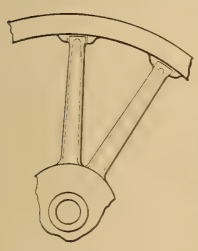


FIG. 3.—A SOLID RIM WHEEL

In fitting up the wheel, the centre is bored out, and the ends of the hub are faced off. It then is taken to the planer, and a centre-guide plate for the hub is made, and bolted to the planer table. Then a boring bar is arranged to bore out the hole and face it off to a given distance from the centre for the shoulder of the arm to rest on. There are small chipping pieces on both inner sides of the receptacle for the arm. They are planed off at the same setting, to the proper and uniform width, and true to the centre. This finishes the centre.

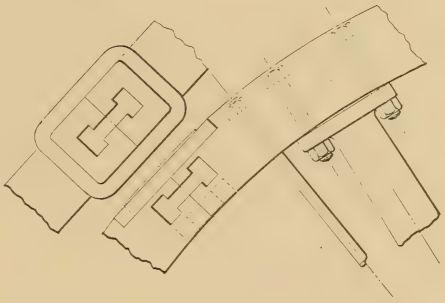


FIG. 2.—A SECTIONAL RIM CAST IRON WHEEL WITH HEAVY LINKS HOLDING THE SEGMENTS TOGETHER

Next the arm goes on the planer and is set true to the average centre, and with a socket on the end of the boring bar with inside cutters the end of the arm is turned off, and the shoulder is faced off to the proper length for the arm to rest on; so at this setting the chipping piece on the upper side of the arm, as it lies on the planer, corresponding with the same in the centre, is planed off, and the average centre of the segment is also carefully taken and correctly worked.

After the arms are thus far finished, they are placed on the planer again, the other side up, and a socket is made to fit over the end of the arm which goes into the socket and against the shoulder. On the opposite end of the socket is a hole bored, say, 1½ inches or 2 inches in diameter. The length of arm must be, from the centre of the hole to the

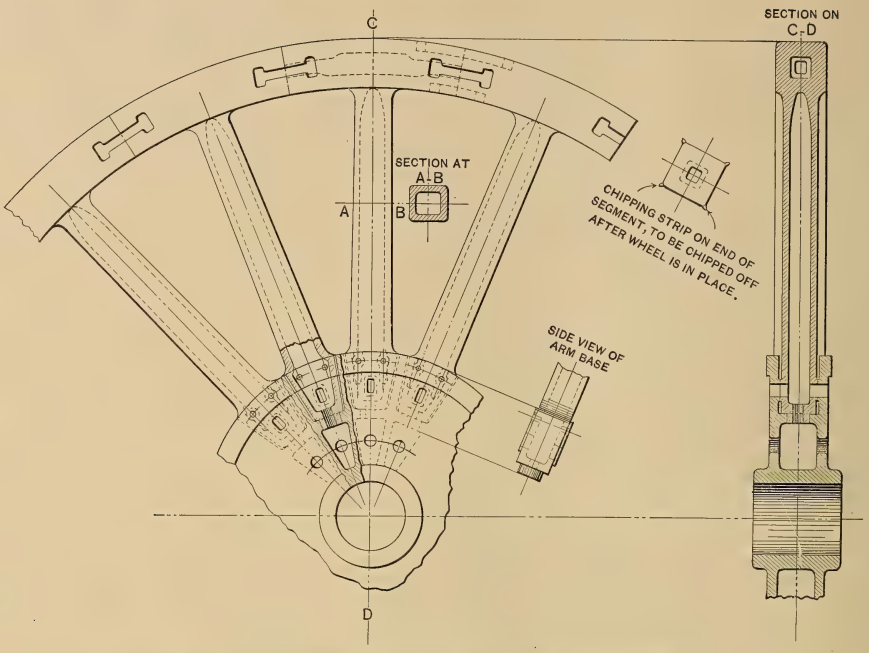


FIG. 4.—THE SAFEST BLOOMING MILL ENGINE FLY-WHEEL

bottom of the socket on which the arm rests, the same as the distance from the face upon which the arm rests to the centre of the hole in the shaft.

Next secure a pin on the planer bed to correspond in size with the hole in the end of the socket piece. Then put the socket on the end of the arm and on the pin; then bolt the arm down true on the side that is planed, and finish to the proper size. When this is done, find the exact length of the segment and set it in line with the centre, and you have the exact angle, and when all is done correctly the wheel will fit together without a chisel or a file being used on it, and will run true, without turning, minus the irregularities in the castings.

There are no abrupt changes in the thickness of the castings, thus avoiding as much as possible the liability of the strains. The joints in the segments are generally the weak part of the wheel. In this respect a wheel made from this drawing will be stronger than the original, as the tees in the segments in the wheel now in use were made of wrought iron, and will probably not stand over 50,000 pounds tensile per square inch, while in this wheel, if the writer were to build another, he would use steel that would stand at least 85,000 pounds tensile. This would make the joints practically as strong as the segments.

It will be noticed in the illustration that there is a space in the centre of about ¼ inch in front and rear side of each arm. This is filled with oakum and driven hard, after the wheel is finished and in place, to keep the arm from yielding in the direction of the strain, and at the same time greatly lessens the work of fitting up the wheel. The 1¾-inch round holes shown, through the centre and arm, are reamed out, and steel pins made and turned so that they will drive in snugly.

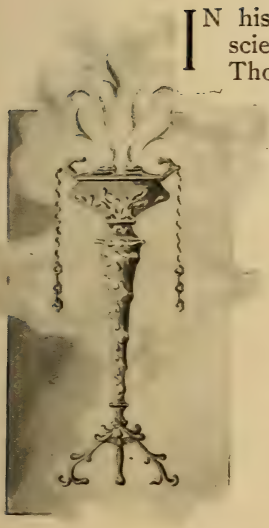
The bolt shown in the segment in Fig. 2 does not belong to this wheel, but was simply put in there to show the plan that, in many cases, was adopted to make the wheels more secure, and is used to some extent at this time.

LORD KELVIN

A BIOGRAPHICAL SKETCH

By J. D. Cormack, B. Sc., M. L. E. E.

The First Part of This Sketch Appeared in the May Number



IN his dual capacity as a scientist and a sailor, Thomson recognised the deficiency of trustworthy and adequate knowledge of the tides and launched forth on a grand scheme for investigating and predicting the tides at all the ports in the world. The theory of the tides was known. It had been well worked out by Laplace, Airy and others, who showed that the height of the tide at any time and at any place could be found by adding together the effects at that time of a certain number of constituent tides, each a simple harmonic function of the time. In other words, the tide-time curve was the sum of a certain number of constituent sine curves. The scheme involved the finding, from years of observation at the different ports, of the total tide-curve for each port, and the determination from it of the constituent tide-curves. The twenty chief constituents, requiring forty constants to specify them, may be determined from observations extending over one year.

In 1867 he brought the subject before the British Association, with the result that a committee, which afterwards rendered valuable service, was formed "for the purpose of promoting the extension, improvement, and harmonic analysis of tidal observations." The ingenious instruments devised by him, and extensively used to facilitate the recording and perform the calculations mechanically, are fully described in the Proceedings of the Institution of Civil Engineers for 1881, in his paper on "The Tide Gauge, Tidal Harmonic Analyser, and Tide Predicter."

Perhaps no science owes more to Lord Kelvin's genius than that of thermodynamics. We may regard the years from 1840 to 1850 as the dawn of the modern dynamical theory of heat,—that transition period which witnessed the death of the old idea, heat,—"a substance, invariable in quantity, not convertible into any other element, and incapable of being generated by any physical agency," and the birth of the new and all-pervading idea, heat—"a mode of motion."

In 1820 Carnot had given forth his "Theory of the Motive Power of Heat," but he was in advance of the age and little attention was paid to it until about a quarter of a century afterwards. The experiments of Rumford and Davy had thrown discredit on the existing ideas regarding the nature of heat, and Carnot fully appreciated the difficulties and possibilities raised by them; but, nevertheless, for want of a better, he accepted the "material" theory.

Carnot's ideal engine, in which any working substance could be used, produced power in the transference, by a certain steady cycle of operations, of heat from a hot body, (the source), to a cold body, (the condenser). It required, as its fundamental axiom, the assumption that the heat taken in at the source is equal in quantity to that given out by the condenser. Motive power was considered to be derived from heat

in much the same way as from water flowing from a higher to a lower level; heat at a high temperature possessing greater capacity for mechanical effect; and though for years engineers had

PHOTO BY ANNAN

LORD KELVIN IN 1896

used condensing engines, strange as it may now seem, they tacitly admitted that, in Carnot's engine, the heat which left the boiler entered the condenser undiminished.

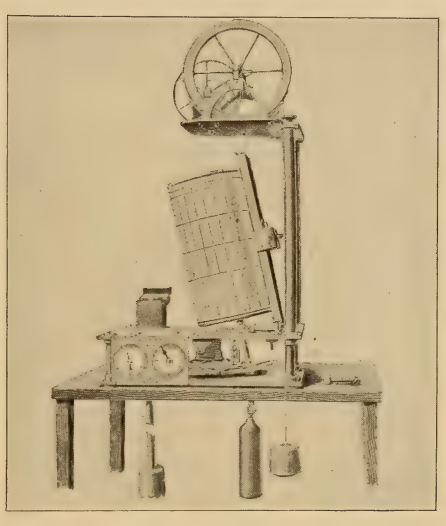
In a paper to the *Philosophical Magazine*, in 1848, Thomson proposed an absolute thermometric scale, founded on Carnot's theory, and independent of the properties of any particular substance. He modified it in 1854 so as to make it more convenient in practice. The scale has proved extremely useful in thermodynamic investigations, and possesses the additional advantage that it agrees with the practical standards,—air thermometers,—as closely as they do among themselves. The paper gave abundant evidence of the state of doubt then prevailing. He referred to some of Joule's experiments, and appealed

for further and fuller experimental investigations on the nature of heat.

In the same year, in a paper on "The Theory of Electro-magnetic Induction," he gave a simple proof of Neumann's theorem on the intensity of the current induced in a closed conductor by the relative motion of a magnet. He based it on the axiom that the amount of work expended in producing the relative motion on which the electro-magnetic induction depends must be equivalent to the mechanical effect lost by the current induced in the wire; and showed, first, that "the amount of mechanical effect continually lost or spent in some physical agency (according to Joule, the generation of heat) during the existence of a galvanic current in a given closed wire is, for a given time, proportional to the square of the intensity of the current."

In the following year he gave a full account of Carnot's theory to the Royal Society of Edinburgh, and obtained, from examination of results of Regnault and other observers, a striking confirmation of the theory so far as regards different working substances. At the same meeting his brother, Professor James Thomson, gave a modified specification of Carnot's cycle which obviated the necessity of considering heat as material, and also showed how, according to the theory, the freezing point of water ought to be lowered, by application of pressure, 0°.0075 C. for each additional atmosphere. This striking prediction was experimentally verified by Professor William Thomson in the following year. Again Thomson pointed out the difficulties in the way of the theory, and emphasised the necessity of experiments which would supply either explanations or an entirely new basis for the theory of heat. The paper contained also an instructive table of the efficiency and economy of the best engines and boilers of that date, comparing the actual and theoretical duties; and it is interesting to note that he suggested, as a means of obtaining a closer approach to the theoretical duty, the use of what is now known as superheated steam.

Meanwhile, Mayer, in Germany, had been experimenting on the relations existing between heat and work, and Joule was patiently and incessantly adding experiment after experiment to his grand series on the mutual relations of electric, magnetic, and chemical actions, and work and heat, forging link after link in the chain which now binds them together in one connected whole. One of Joule's results,—unfortunately the only one with which his name is popularly associated,—was the discovery of the numerical relation between work done and heat produced. His results seemed to be entirely at variance with



LORD KELVIN'S TIDE GAUGE

Carnot's theory, which he accordingly denied, though it was confirmed in many remarkable ways by experiment. One of the obstacles in the way of accepting Joule's ideas lay in the absence of special experiment to show the direct conversion of heat to work with the same numerical result. It seemed to stand, Joule *vs.* Carnot.

The position of matters at the time is well shown in the following extract from a speech delivered by Lord Kelvin when he unveiled the Joule statue in Manchester Town Hall on December 17, 1893:—

"I can never forget the British Association at Oxford in 1847, when, in

one of the sections, I heard a paper read by a very unassuming young man who betrayed no consciousness in his manner that he had a great idea to unfold. I was tremendously struck with the paper. I, at first, thought that it could not be true, because it was different from Carnot's theory, and immediately after the reading of the paper I had a few words of conversation with the author, James Joule, which was the beginning of our forty years' acquaintance and friendship.

"On the evening of the same day that very valuable institution of the British Association,—its conversazione,—gave us opportunity for a good hour's talk and discussion over all that either of us knew of thermodynamics. I gained ideas which had never entered my mind before, and I thought I, too, had suggested something worthy of Joule's consideration when I told him of Carnot's theory. Then and there, in the Radcliffe Library, Oxford, we parted, both of us, I am sure, feeling that we had much more to say to each other and much matter for reflection in what we had talked over that evening.

"But what was my surprise a fortnight later when, walking down the valley of Chamounix, I saw in the distance a young man walking up the road towards me and carrying in his hand something which looked like a stick, but which he was using neither as an Alpenstock nor as a walking stick. It was Joule with a long thermometer in his hand, which he would not trust by itself in the *char-à-banc* coming slowly up the hill behind him, lest it should be broken. But there, comfortably and safely seated on the *char-à-banc*, was his bride,—the sympathetic companion and sharer in his work of after years. He had not told me in Section *A* or in the Radcliffe Library that he was going to be married in three days; but now, in the valley of Chamounix, he introduced me to his young wife. We appointed to meet again a fortnight later, at Martigny, to make experiments on the heat of a waterfall (Sallanches) with that thermometer, and afterwards we met again and again and again, and from that time, indeed, remained close friends till the end of Joule's life."

It is noteworthy that the chief workers in the new field, Joule, Thomson, Helmholtz, Rankine, and Clausius, were all young men under thirty, Thomson being the youngest. The materials were hot, the man was ready, and in 1851 Thomson struck the blow that welded heat and dynamics together, and created the new science of thermodynamics. His paper to the Royal Society of Edinburgh, "On the Dynamical Theory of Heat," reconciled Joule and Carnot, scattered all doubts, placed the whole subject on a satisfactory and scientific basis, and gave a wonderfully complete mathematical treatment. The relations between heat and electricity were at once subjected to scrutiny in the new light and also received mathematical consideration.

One of the first fruits was Thomson's prediction that an electric current, in passing through an unequally heated conductor, must produce different thermal effects according as it passed from hot to cold or from cold to hot in the same metal. This phenomenon,—the "Thomson effect,"—predicted from theoretical considerations, was experimentally shown by him to exist three years later in one of an extensive series of investigations on the thermo-electric properties of different metals, and the alteration produced by mechanical and magnetic strains. The thermo-electric diagram which exhibits so clearly all the effects and their relations was first suggested by Thomson.

Other interesting conclusions were made as a result of the new thermodynamic theory. For example, from his value of Carnot's function, calculated from Regnault's experiments, he showed that the existing determinations of the specific heat of air at constant pressure were from 10 to 20 per cent. too high, and gave as its value 0.2374, which is almost exactly the value found experimentally by Regnault in the following year.

In 1852 he undertook, with Joule, a series of experiments on the thermal

effects of fluids in motion, which extended over a period of about ten years and yielded many valuable results. They showed the very approximate truth of Mayer's hypothesis that the heat evolved from air, compressed and kept at a constant temperature, is mechanically equivalent to the work done upon it, and enabled a comparison of the scales of the air and absolute thermometers to be effected. Taken together with Regnault's results on the latent heat and pressure of saturated steam, they gave increased strength to the suspicion entertained by Thomson, Rankine and others that the density of steam deviated very considerably from what was given by the ordinary gaseous laws.

Thomson's paper on "The Dynamical Theory of Heat" and its exposition of the grand principle of the conservation of energy, for which Joule furnished the experimental foundation, was followed immediately by other papers on kindred subjects. In the same year, 1851, in his paper "On the Mechanical Theory of Electrolysis," he showed how to determine the electromotive force of a primary battery,—a Daniell cell,—from the chemical actions going on within it, and gave also for the first time the true law for the efficiency of an electromotor. During the next two years,—a period of remarkable activity,—he gave a number of papers on such subjects as on the sources of heat generated by the galvanic battery; on the mechanical action of radiant heat or light; on the power of animated creatures over matter; on the sources available to man for the production of mechanical effect; on the mechanical values of distributions of electricity, magnetism and galvanism; and on the restoration of mechanical energy from an unequally heated space.

In 1852 he enunciated the doctrine of "The Dissipation of Energy." It was the outcome of the consideration of the reversibility of processes for the transformation of energy, and was founded on the axiom on which he based his proof that no engine could be more efficient than a perfectly reversible one:—

"It is impossible by means of inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects. If this axiom be denied for all temperatures, it would have to be admitted that a self-acting machine might be set to work and produce mechanical effect by cooling the sea or earth, with no limit but the total loss of heat from the earth and sea, or, in reality, from the whole material world."

The following extracts are interesting:—"The considerations of ideal reversibility by which Carnot was led to his theory, and the true reversibility of every motion in pure dynamics have no place in the world of life. Even to think of it (and on the merely dynamical hypothesis of life we can think of it as understandingly as of the origination of life and evolution of living beings without creative power), we must imagine men with conscious knowledge of the future, but no memory of the past, growing backward, and again becoming unborn; and plants growing downward into the seeds from which they sprang. But the real phenomena of life infinitely transcend human science, and speculation regarding consequences of their imagined reversal is utterly unprofitable. Far otherwise, however, it is in respect of the reversals of the motions of matter, uninfluenced by life, a very elementary consideration of which leads to the full explanation of the theory of the dissipation of energy. . . .

"Exhaustive consideration of all that is known of the natural history of the properties of matter, and of all conceivable methods for obtaining mechanical work from natural sources of energy, whether by heat engines, or electric engines, or water-wheels, or windmills, or tidemills, or any other conceivable kind of engine, proves to us that the most perfectly designed engine can be only an approach to the perfect engine, and that the irreversibility of actions connected with its working is only part of a physical law of irreversibility ac-

Prof. E. Mascart Prof. W. C. Unwin Lord Kelvin Dr. Coleman Sellers Col. Th. Turrettini

THE INTERNATIONAL NIAGARA FALLS COMMISSION

cording to which there is a universal tendency in nature to the dissipation of mechanical energy; and any partial restoration of energy is impossible in inanimate material processes, and is probably never effected by means of organised matter, either endowed with vegetable life, or subject to the will of an animal."

A popular statement of the doctrine is contained in the following quotation:—"During any transformation of energy of one form into energy of another form there is always a certain amount of energy rendered unavailable for further useful application. No known process in nature is exactly reversible,—that is to say, there is no known process by which we can convert a given amount of energy of one form into energy of another form, and then, reversing the process, reconvert the energy of the second form thus obtained into the original quantity of energy of the first form.

"In fact, during any transformation of energy from one form into another, there is always a certain portion of the energy changed into heat in the process of conversion, and the heat thus produced becomes dissipated and diffused by radiation and conduction. Consequently, there is a tendency in nature for all the energy in the universe, of whatever kind it may be, gradually to assume the form of heat, and, having done so, to become equally diffused. Now, were all the energy of the universe converted into uniformly diffused heat, it would cease to be available for producing mechanical effect, since for that purpose we must have a hot source and a cooler condenser. This gradual degradation of energy is perpetually going on, and, sooner or later, unless there be some restorative power of which we, at present, have no knowledge whatever, the present state of things must come to an end."

In 1852, also, in a paper on "The Economy of the Heating or Cooling of Buildings by means of Currents of Air," he proposed and investigated methods by means of which cooling and heating could be performed with the consumption of a much smaller quantity of coal than was required by direct means. For heating purposes, air from the atmosphere was expanded in a cylinder and sent to a receiver, its temperature being maintained constant by heat drawn from the surroundings. It was then heated by compression in a second cylinder and discharged. For cooling, the reverse cycle was to be used; air was compressed in one cylinder and discharged to the receiver, the surroundings keeping the temperature constant. It was then cooled by expansion in, and discharged from, the second cylinder. The method of heating remains yet unrealised; but the method of cooling has been realised in several refrigerators.

Thomson's papers on "Transient Electric Currents," which were given in 1853 to the Glasgow Philosophical Society and to the *Philosophical Magazine*, contain a number of interesting results and suggestions. Here he suggests a method of measuring electrostatic potentials by weighing, which he afterwards adopted in various instruments. Here also, proceeding from the equation of energy, he investigated the discharge of a condenser through a resistance possessed of self-induction, and showed that, under certain circumstances, the discharge would be oscillatory in character. He suggested that this might be an explanation of the multiple flashes of lightning which sometimes occur.

Helmholtz had previously come to suspect surgings to exist from consideration of the experiments of Reiss and of Wollaston on the magnetic and electrolytic effects of the discharge. Thomson's paper also suggests a method of investigating the discharge by means of a revolving mirror, which Feddersen, in 1861, successfully adopted. The phenomenon of oscillatory discharge is rendered all the more interesting because it formed the starting-point from which Hertz commenced his later brilliant researches on electric waves.

Notwithstanding his labours and successes in other fields, which alone would place him in the first rank of the men of science of the century, perhaps it is

with the theory and the practical applications of electricity and magnetism that Lord Kelvin will be forever most prominently, as he is most popularly, associated. Most of his earlier electrical papers were on electrostatics, and in 1845, when twenty-one years old, he contributed two papers to the *Liouville Mathematical Journal.* In one of these he discussed Sir William Snow Harris's experiments, to which the Copley Gold Medal of the Royal Society had been awarded.

These were apparently at variance with Coulomb's laws, but Thomson showed that they really confirmed them when proper account was taken of the circumstances under which the experiments were performed. In this paper we see also the first attempt to found the mathematical theory of electricity on Faraday's discovery of induction. The second paper showed how it was possible to solve problems on the distribution of electricity on conductors by the use of what he called "electrical images," which gave extremely simple and elegant solutions to difficult problems. Two years later he gave another paper on the same subject to the British Association.

At this time progress in electric investigation was greatly hampered and comparison of results rendered difficult and tiresome by the various arbitrary electric units adopted by different experimenters. Gauss had already propounded the absolute system of dynamical and magnetic units which have proved of such immense value, and in 1851 Weber extended it to electromagnetism. Thomson immediately welcomed and adopted Weber's units, and in the same year prepared a paper on "Applications of the Principle of Mechanical Effect to the Measurement of Electromotive Forces, and of Galvanic Resistances in Absolute Units."

Weber's unit of electromotive force was derived from the idea of cutting lines of force. Thomson introduced the idea of mechanical effect, and showed that "if a current of uniform strength be sustained in a linear conductor, and if an electromotive force act in this conductor in the same direction as the current, it will produce work at a rate equal to the number measuring the force multiplied by the number measuring the strength of the current." Here also, for the first time, the electromotive force of a Daniell cell is calculated in absolute units, and we find the novel method of measuring the absolute resistance of wire by finding the heat produced in it by a known current passing through it,—the beginning of absolute electric measurements.

Thomson warmly advocated the adoption of the absolute system, both for purposes of investigation and for telegraphic work, which was then the only important practical application of electricity; and in 1861 he obtained the appointment of a committee of the British Association on electrical standards. In this committee he was a prominent and indefatigable member, and to its labours during ten years must be ascribed much of the rapidity of the progress in electric lighting and transmission of power, the pioneers of which found themselves, when their time came, possessed of a perfect system of absolute units and realised practical standards, which suited their needs, and simplified the required formulæ and calculations.

The adoption of the units was one desirable end to be gained, but instruments to make accurate measurements simply and conveniently had yet to be devised. Lord Kelvin's feelings on the subject of measurement generally are well seen in the following quotation:—

"I often say that when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be."

In 1853 he showed how to construct an instrument to measure electrostatic potential in absolute units; and two years later he carried it into practice, exhibiting his "absolute electrometer"

to the British Association. With this instrument absolute electrostatic measurements were made for the first time in 1860 during his researches on the electromotive force required to produce a spark in air. Briefly, the essential part of it consists of two insulated circular brass plates; one is capable of being moved nearer or further away by an ascertainable amount; the other is fixed, and has a circular hole in the centre into which fits, just avoiding contact, a small aluminium disc, suspended by miniature coach springs, and in electrical communication with it.

When the instrument is used heterostatically, an independent source of electrification is required, and this is furnished by a small induction machine, —the well-known Thomson "replenisher." A small, independent, attracted disc gauge, similar in principle to the main gauge, is used to show if the electrification remains constant during an experiment. The fixed plate and the disc are connected to the replenisher and the movable plate, earthed and brought into such a position that the force of attraction between it and the disc brings the disc to its normal position against the action of its supporting springs, which exert on it a measurable force. The moving plate is then connected to the body or source whose potential it is desired to measure, and its distance is altered till it again brings the disc to its normal position. The distance through which the plate is moved, the force due to the springs, and the area of the disc require to be known to calculate the potential in absolute units.

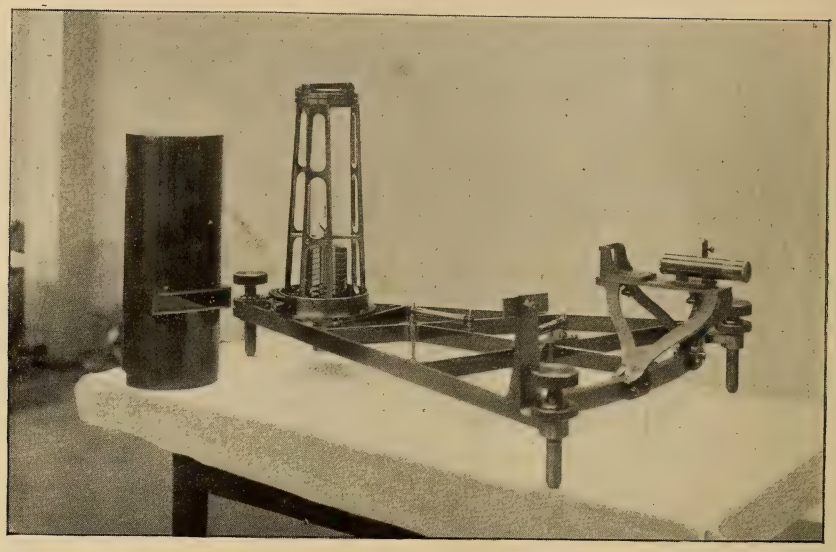
The same principle of measuring the force of attraction on a disc is used in his long-range electrometer for measuring potentials from 4000 to 80,000 volts, and in his portable electrometer, which was designed to be as small and compact as possible and convenient to be carried about from place to place for rapid observations of atmospheric electricity. He used another electrometer, with the same general features, in his experiments to find the number of electrostatic units in an electro-magnetic unit of quantity, which was proved to be, as Maxwell's electro-magnetic theory required that it should be, equal to the velocity of light in air within the limits of accuracy of observation.

In the Transactions of the Pontifical Academy of Rome for 1857, there appears a description of Lord Kelvin's first divided ring electrometer, which afterwards developed into the well-known Thomson quadrant electrometer,—an instrument invaluable in scientific research and indispensable in every decently equipped laboratory. It is impossible here to give even the briefest description of these well-known instruments; they are described in most text-books.

In 1867 Sir William Thomson reported to the British Association that he had constructed a series of electrometers capable of measuring potentials from $\frac{1}{100}$ to 100,000 Daniell cells, these measurements being reducible to absolute measurements by comparison with one instrument of the series. The importance of this enormous stride in the practice of electrical measurement is well seen from the statement in the committee's report that they "surpass every expectation of practical electricians and furnish a new engine for electrical research."

The unit of resistance was the first to receive attention, and in 1863-'64 experiments were conducted by Clerk Maxwell and Fleeming Jenkin to determine, by a method proposed by Thomson, the value of the absolute standard and to form from that a material standard of resistance. A year later the committee distributed thirty-three copies of the provisional B. A. unit to be used as standards till a closer approximation to the true ohm should be made. The B. A. unit is still to be met with in resistance boxes; but it was displaced, first by the legal ohm of the Paris Congress in 1882, and afterwards in Great Britain by the Board of Trade ohm, proposed in 1891 and finally adopted in 1894.

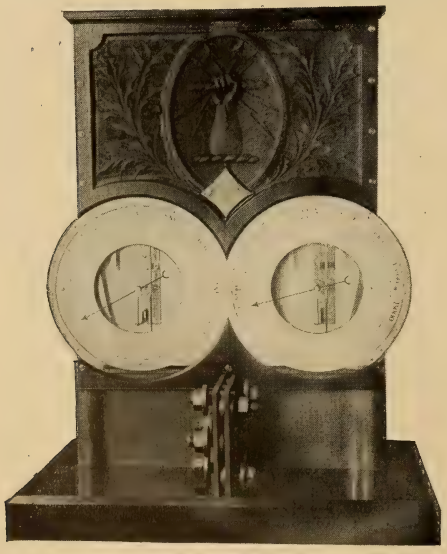
Cable telegraphy, undoubtedly, gave the starting impulse to scientific electric measurement. In 1858 it had been put



A 100-VOLT STANDARD MULTICELLULAR VOLTMETER

into practice in ascertaining the copper and insulation resistance and the capacity of cables; but it was not till the close of the British Association committee's work, in 1869, that it became common in Great Britain and America, and not till after the Paris Congress was it usual on the Continent.

It was natural that Lord Kelvin should take a leading part in the rise and development of electric lighting and transmission of power, as well in the generation of electricity as in its measurement. Besides other primary batteries he has given a standard Daniell cell and a tray Daniell for large currents. Various forms of open coil dynamos were proposed by him, and in 1881 he patented a wave-wound disc armature, without iron core.



AMPÈRE GAUGE FOR THREE-WIRE CIRCUIT, 15,000 AMPÈRES ON EACH SIDE

Ferranti independently invented a somewhat similar machine shortly afterwards, and together they introduced the Thomson-Ferranti alternator, which immediately created a great sensation, as it produced results far in advance of any previously attained, giving about five times the usual output per ton weight. He made numerous contributions to the theory of dynamos and the windings of armatures and field magnets, and drew attention to, and gave a formula for, the pressure produced on the bearings by the gyrostatic action of the armature when the shaft changes its direction, as in a car turning a curve or in a ship rolling.

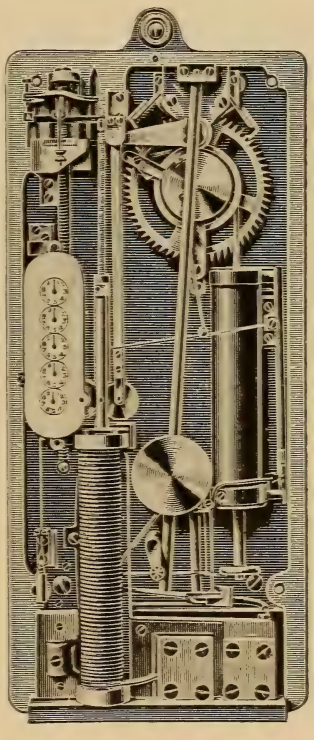
The transmission and distribution of electrical energy also attracted his attention. In 1879, when giving evidence on electric transmission before a Parliamentary committee, he showed that it was possible to transmit with economy

21,000 H. P. under a pressure of 80,000 volts to a distance of 300 miles. Two years later he gave a paper to the British Association on "The Economy of Metal Conductors of Electricity," which contained his well-known economic law, applicable, with the necessary changes, to many other questions of economy, that, if the capital outlay be proportional to the weight of the metal in the cable, the most economical area of the conductor is that for which the annual interest on capital outlay equals the annual cost of the energy wasted in it.

A well-deserved tribute was paid to him when he was appointed, in 1890, to the chairmanship of the International Niagara Commission, which examined, reported on, and awarded prizes to plans for the generation and transmission of power from Niagara Falls. The commission finally selected for this great undertaking a system which has since proved entirely successful; but not the least valuable part of its work was the collection and comparison of all the most recent information and practical results together with the best designs procurable in rope, hydraulic, pneumatic, and electric transmission. Lord Kelvin is associated with a smaller undertaking of the same nature nearer his home, the generation of power from the Falls of Foyer and its utilisation to manufacture aluminium by the British Aluminium Company.

The first Faure secondary batteries brought to Great Britain were submitted to him for testing, and his house at the university was the first in Great Britain to be lighted electrically, from top to bottom, by incandescent lamps. The whole installation was complete with its gas engine, batteries and shunt-wound dynamo and switches, automatic devices, and other instruments of his own design. In the earlier days of electricity supply companies and central stations Lord Kelvin's aid was considered indispensable in every undertaking, and even to-day, when practice is more formulated, he is always busy with plans for some new scheme.

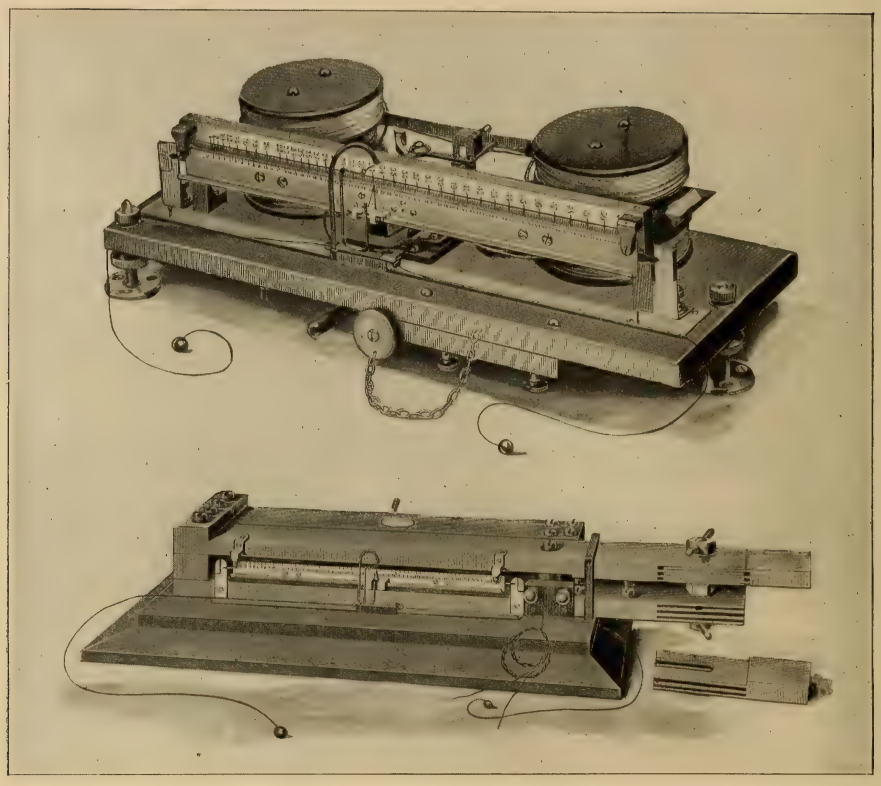
It may safely be said that no one has invented more or better electric measuring instruments for standard, laboratory, or commercial use. They are covered mainly by sixteen master patents, dating from 1881. Of the early instruments the graded and magnetostatic ammeters and voltmeters were based on the tangent galvanometer principle with permanent controlling magnets. In the graded instruments provision was made for a long range, through which measurements could be made by moving the needle box and the controlling magnet



ELECTRICITY SUPPLY METER

to various distances along the axis of the coil.

In the magnetostatics, which are of the Helmholtz double-coil type, variations in the range and corrections for loss of magnetism in the magnets are permitted by the use of two sets of circular magnets which give a uniform field at the centre. One of the most important groups contain standard balances for both alternating and continuous currents, ampère balances to weigh

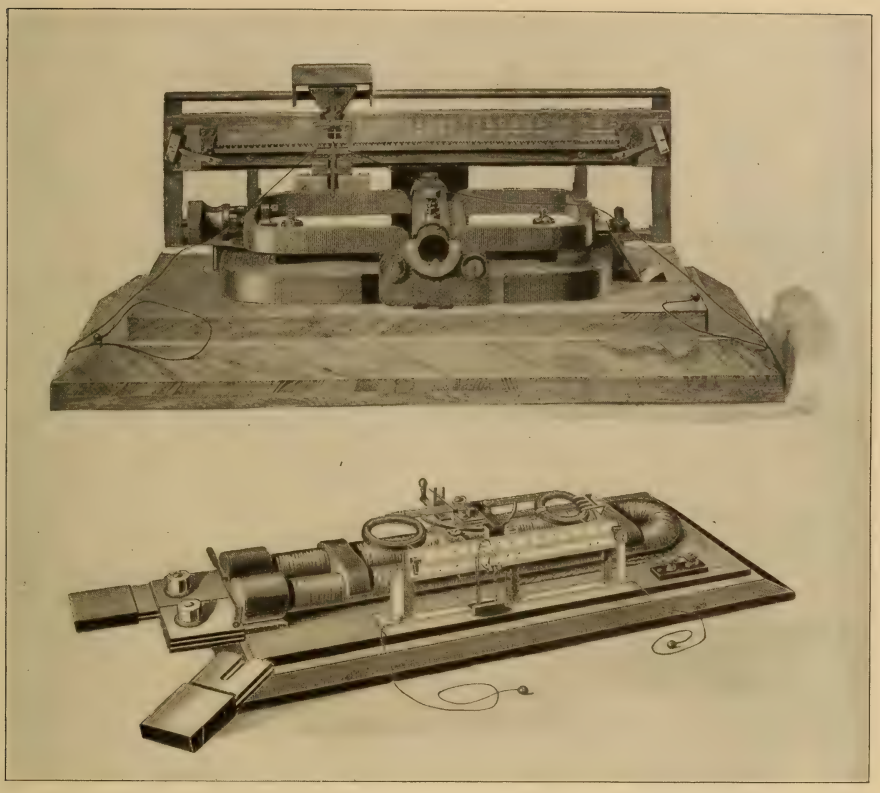


SOME TYPES OF LORD KELVIN'S STANDARD AMPÈRE AND WATT BALANCES

from $\frac{1}{100}$ up to 250 ampères, and watt balances suitable for currents up to 10,000 ampères. These are to be found in laboratories and stations all over the world, and a set has been supplied to the Board of Trade standardising laboratory.

The chief feature of this group of instruments lies in the fact that, as the outcome of ingenuity and good design, they permit the use of what is, undoubtedly, the most accurate method of measuring electric currents,—the weighing of the force between two coils; and combine convenience, accuracy, and rapidity, with absence of liability to derangement even when subjected to somewhat rough usage. In each instrument the mutual force, acting between fixed and movable coils carrying the current, is counterbalanced by moving a weight along a steelyard connected with the movable coils. The steelyard is suspended by filaments of fine copper wire which convey the current to the coils. Each instrument is provided with a set of weights, giving a wide range of readings and allowing the readings to be taken in the most sensitive part of the scale.

In many of Lord Kelvin's voltmeters advantage is taken of the phenomena of electrostatic attractions and repulsions, and the instruments are thus suitable for both alternating and continuous circuits and free from temperature and iron errors. One group of electrostatic instruments,—the multicellular voltmeters,—form a series of standards between 30 and 2500 volts. Here the quadrant electrometer principle is modified to form a convenient commercial instrument. A number of thin, flat, aluminium, paddle-shaped needles are fixed horizontally at equal intervals on a fine platinum-iridium wire. These hang in spaces between two corresponding sets of insulated horizontal

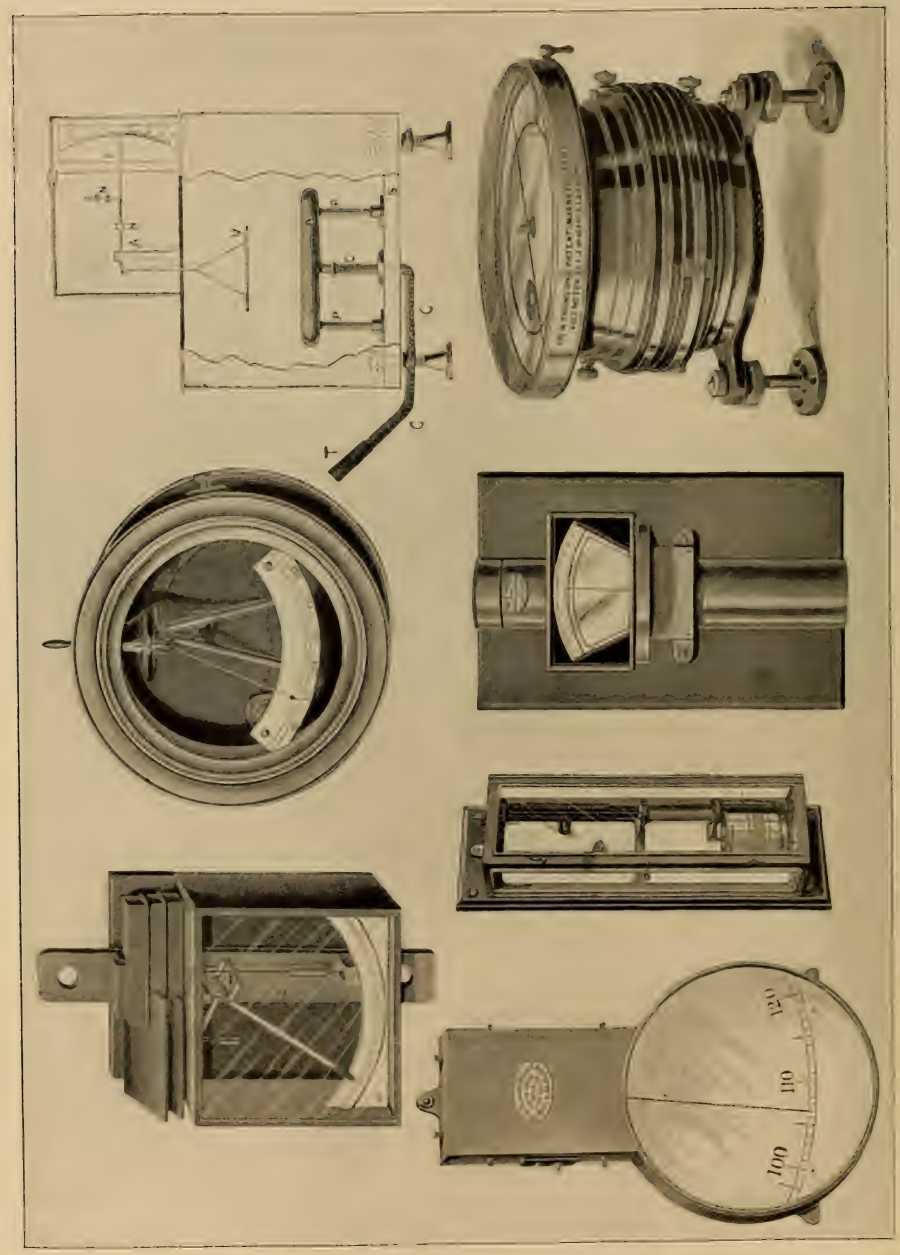


SOME TYPES OF LORD KELVIN'S STANDARD AMPÈRE AND WATT BALANCES

brass segments. A difference of potential existing between the segments and the needles draws them more underneath the corresponding segments against the action of the suspending wire; the deflection is read off on a scale, horizontal in the instruments intended for laboratory use, and vertical in the switchboard pattern. The same principle is applied in the vertical electrostatic voltmeters which are intended for higher voltages,—from 200 to 20,000 volts. There is only one needle, and it is suspended on knife edges so as to move in a vertical plane, the control being gravity.

The new dial electrostatic voltmeters are somewhat similar, but have a number of needles fixed on a spindle running in jewelled bearings. The control is gravity, and for convenience in central station work, the instruments are so arranged as to give a large open scale on each side of the normal voltage. The needle system balances at zero, but when displaced slightly an extra controlling weight is released. The lowest voltage for which the instrument is intended is just sufficient to counterbalance this, and the whole of the scale is thus available for readings within the prescribed limit.

For pressures up to 100,000 volts, the attracted disc principle is used in the electrostatic balance. A fixed plate attracts a movable disc, suspended from one end of a lever, the other end of which moves over a graduated scale. The Kelvin ampère and volt gauges are of the coil and plunger type, with gravity control and knife-edge bearings; the Kelvin central station voltmeters and recording voltmeters are constructed on the same principle. Another series of instruments, including voltmeters and wattmeters, are of



SOME KELVIN AMMETERS, VOLTMETERS, AND WATTMETERS

the double-coil type, with gravity control and knife-edge bearings.

Lord Kelvin's meters are of the periodic integrating coulomb meter type, —that is to say, the current consumed is not continuously added up, but samples are taken at short intervals of a few seconds and integrated, the current being assumed constant during the interval. The instrument consists of three parts,—the coil and plunger for measuring the current, the electrically-driven clock, and the integrating and recording gear. A soft iron plunger is supported inside a solenoid by a long spiral spring connected to one end of a small weighted lever supplied with an auxiliary spring. The adjustment of these is such that the deflection of the plunger is proportional to the current passing through the solenoid, even when the current is small. During each cycle the deflection is recorded by causing the plunger to move over the circumference of a friction wheel. This is the first of the recording train, and its motion is thus proportional to the quantity passing, the current being assumed constant during the cycle.

Pages might be filled with descriptions of numerous other instruments and various pieces of electrical apparatus invented by Lord Kelvin, including rheostats, volta piles, standard air condensers, an astronomical clock, and a water tap. A visit to Messrs. James White's, a glance at the standardising laboratory where lane after lane is hedged with instruments of all kinds, getting the final touches, and a peep into the workshops where 250 men are all busy making apparatus devised by Lord Kelvin, impress one more than a detailed list with the extent and variety of his inventions. It was James White, the founder of the firm, philosophical instrument maker to the university, and thus a successor of James Watt, who constructed the first Kelvin instruments. He has long ago passed away, and there is now no White in the firm.

Lord Kelvin's instruments are easily recognised. Simplicity in construction, ease of inspection and repair of the working parts, convenience in adjustment, geometrical guidance and constraint are all distinguishing features, and, needless to say, accuracy is an essential quality. In his early dealings with instrument makers Lord Kelvin found them possessed of a considerable amount of what he calls "mental inertia." Many of his ideas, being quite opposed to existing practice, were looked upon with doubt; but they proved as successful as they were daring, and often the novelty, as well as the success, lay in the scientific design. One of his mottoes is, "Good workmanship cannot compensate for bad design."

In many instruments we find examples of geometrical guidance and constraint, the principles of which are still comparatively unknown to instrument makers and engineers. Frequent use is made of his "hole, slot, and plane" arrangement, by means of which a piece of apparatus can be removed, returned to exactly the same position, and be quite free from stresses due to temperature or other expansions and contractions. Briefly, the apparatus is provided with three feet, perhaps levelling screws, with rounded ends. One goes into a three-sided pyramidal hole, another into a *V*-groove pointing to the hole, and the third rests on the plane itself. The apparatus and the body on which it rests may then be clamped together, if desired, by means of a spring, or a slightly elastic screw and nut.

There is no space here for more than mere mention of Lord Kelvin's contributions to the mathematical theories of electricity and magnetism, his long and extensive investigations on such subjects as contact electricity and atmospheric electricity and the well-known resistance, capacity, insulation and other tests with which his name is associated.

The experiments by which he proved his prediction of the electrical convection of heat formed the starting-point of a series of investigations on the electrodynamic qualities of metals, the results of which were given in his Bakerian lecture to the Royal Society in 1856, and in further papers in 1875 and

PHOTO BY FIELD, GLASGOW

EXHIBIT OF LORD KELVIN'S INVENTIONS IN THE UNIVERSITY LIBRARY AT THE JUBILEE CELEBRATIONS IN 1896

1878. The eagerness with which he himself sought knowledge from experiments, and the enthusiasm which he imparted to his students, led, at the commencement of these investigations, to the establishment of his "volunteer laboratory corps" and the transformation of an unused wine cellar in the Old College into the first students' physical laboratory in the world.

The constitution of matter and the size of atoms have always been subjects of great interest to him. In 1862 he showed, for the first time, how, from measurements in contact electricity, a limit could be given to the size of atoms, and afterwards, proceeding on four different lines of argument, founded on experimental results, he showed the very high degree of probability that, "in any ordinary liquid, transparent solid, or seemingly opaque solid, the mean distance between the centres of contiguous molecules is less than the one-five-millionth and greater than the one-one-millionth of a centimetre.

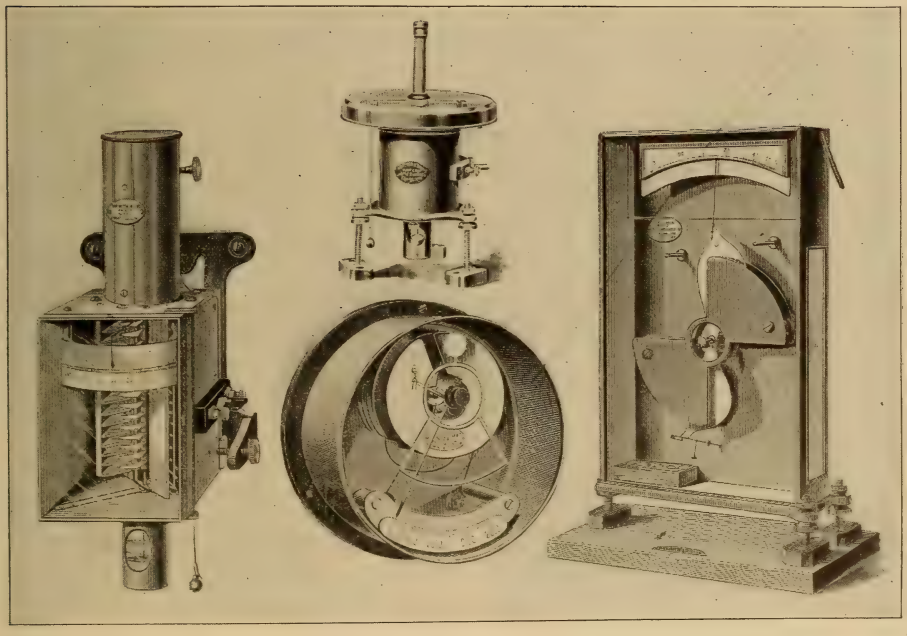
To form some conception of the degree of coarse-grainedness indicated by this conclusion, imagine a globe of water or glass, as large as a football, to be magnified up to the size of the earth, each constituent molecule being magnified in the same proportion. The magnified structure would be more coarse-grained than a heap of small shot, but probably less coarse-grained than a heap of footballs.

Speculations and calculations regarding ether and the nature of electric and magnetic force have formed the substance of many papers. A few weeks after assuming the duties of his chair in 1846 he gave a "Mechanical Representation of Electric, Magnetic and Galvanic Forces," which was published in the following year, and in 1890 he extended it so as to include magnetic induction. For this purpose, he assumed the ether to be incompressible and without elastic rigidity, but to have "a *quasi* rigidity depending on an inherent *quasi* elastic resistance to absolute rotation," and he explained, in a paper given in the same year, "On a Gyrostatic Adynamic Constitution for

'Ether,'" how such a medium could be realised mechanically.

As far back as 1854 he showed that, taking Pouillet's data on solar radiation, the mechanical value of a cubic mile of sunlight is 12,050 foot-pounds; and estimated that a cubic mile of the luminiferous medium contains not less than 1-1060 of a millionth of a pound of matter.

He himself tells how these subjects have been uppermost in his mind for more than fifty years, and if it has not yet been permitted him to reach his goal and wrest from nature these profound secrets, at least his efforts have been noble, and through them many



SOME ELECTROSTATIC VOLTMETERS

difficulties have been cleared away and the path has been made easier for further progress. It is touching to read the confession of failure that he made in an hour of triumph,—the celebration of his professorial jubilee:—

"But when I think how infinitely little is all that I have done, I cannot feel pride; I see only the great kindness of my scientific comrades, and of all my friends, in crediting me for so much. One word characterises the most strenuous of the efforts for the advancement of science that I have made perseveringly during fifty-five years; that word is failure. I know no more of electric and magnetic force or of the relation between ether, electricity, and ponderable matter, or of chemical affinity than I knew and tried to teach to my students of natural philosophy fifty years ago in my first session as professor. Something of sadness must come of failure; but in the pursuit of science, inborn necessity to make the effort brings with it much of the *certaminis gaudia*, and saves the naturalist from being wholly miserable,—perhaps even allows him to be fairly happy,—in his daily work."

Elasticity, hydrodynamics, the vortex theory, and all branches of mathematical physics have received numerous contributions from him, and pure mathematics has been enriched by many papers. In all, he has written about three hundred, but one does not marvel so much at the number as at their varied nature and comprehensiveness.

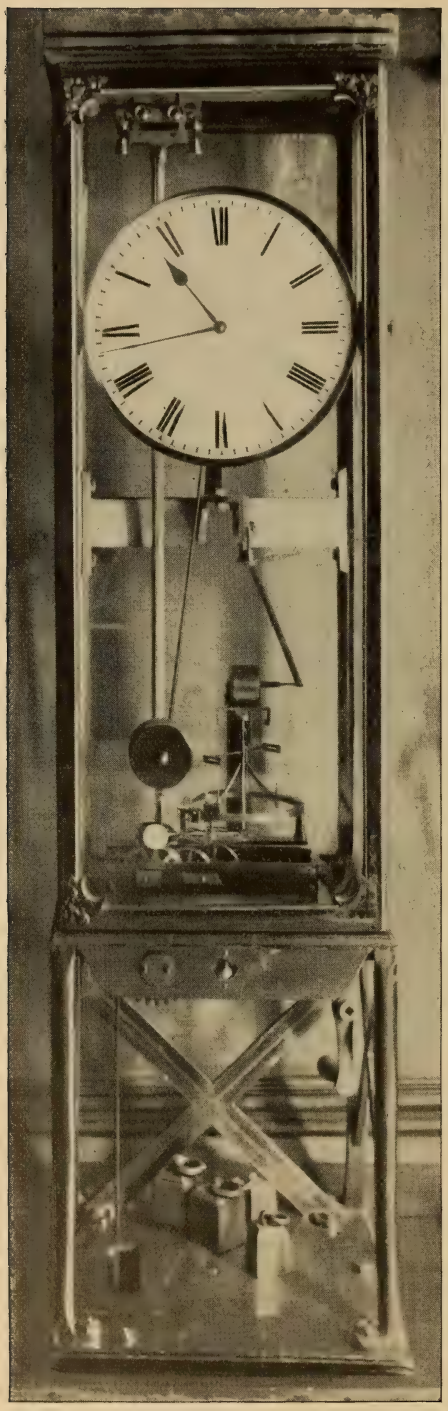


PHOTO BY ANNAN

ASTRONOMICAL CLOCK

Many have been collected and form three volumes of mathematical and physical papers and one volume of papers on electrostatics and magnetism. There are, in addition, three volumes of popular lectures and addresses, and also the Baltimore lectures on "The Wave Theory of Light," which he delivered in 1884 at Johns Hopkins University. Articles in "Nichol's Cyclopædia" and in the "Encyclopædia Brittanica" have come from his pen.

One grand contribution which he gave, with Professor Tait, of Edinburgh, consists of the two volumes of the celebrated "Thomson and Tait's Treatise on Natural Philosophy," which appeared in 1867, and their "Elements of Natural Philosophy," published in 1872. From 1846 to 1853 he was editor of the *Cambridge Mathematical Journal*, and for the past twenty-five years he has been a joint editor of the *Philosophical Magazine*.

Lord Kelvin's writings are as easily recognised as his instruments. Even in his more mathematical papers there is an individuality of style. Accuracy in statement is a distinguishing characteristic, while in his popular lectures he constantly extracts information and illustration from commonplace things as well as from art, literature, and philosophy, both new and old. One of the presidents of the Royal Academy expressed his firm conviction that Lord Kelvin thinks in algebra. Sometimes when he comes to embody his conceptions in words, his hatred of ambiguity and love of strict accuracy in speech as well as in thought and the translation of mathematical formulæ into words, lead to intricate and lengthy sentences (two hundred words is not uncommon) and the manufacture and introduction of words "not at present to be found in the dictionary."

His scientific papers, however much they may bristle with mathematical expressions, are always brightened with some beautiful analogy or some practical application. Here lies the chief charm of his work as well as its outstanding feature. He has striven from the beginning to break down the bar-

rier which existed between science and practice, to submit speculative science to experiment, and to base scientific theory on experimental facts. His own words express best his attitude and feelings on the relations between science and practice.

"There cannot," he says, "be a greater mistake than that of looking superciliously upon the practical applications of science. The life and soul of science is its practical application, and just as the great advances in mathematics have been made through the desire of discovering the solution of problems which were of a highly practical kind in mathematical science, so in physical science many of the greatest advances that have been made from the beginning of the world to the present time have been made in the earnest desire to turn the knowledge of the properties of matter to some purpose useful to mankind."

A CORNER IN LORD KELVIN'S LIBRARY

His influence on scientific thought and work during the latter half of the century springs not only from his publications, but from his teaching in the University of Glasgow; and scattered all over the world are men, now in the first rank of workers in natural philosophy, who can look back to the days when, in his classroom and laboratory, they first caught his inspiration and opened their eyes to scientific truths. His junior class usually consists of 200 students,—a heterogeneous collection preparing for all the professions, some interested in the subject, some chiefly in examinations.

It is, perhaps, at the lecture table that Lord Kelvin displays most of his characteristics. In the two lectures per week, which he delivers to the junior class, he contrives to touch on most of the important points of his subject, passing from one to the other with a rapidity bewildering to lazy or ill-trained students who prefer the beaten track. On such members his digressions, often the most fascinating as well as the most valuable part of his lectures, are, alas, almost lost. His master mind, soaring high, sees one vast connected whole, and, alive with enthusiasm, with smiling face and sparkling eye, he shows

THE LECTURE THEATRE AT THE UNIVERSITY OF GLASGOW

the panorama to his pupils, pointing out the similarities and differences of its parts, the boundaries of our knowledge and the regions of doubt and speculation. To follow him in his flights is real mental exhilaration, a revelation and a keen delight to the better students, and the eyes of even the dullest lift at times from a seeming weary endless road and see the glory of the view.

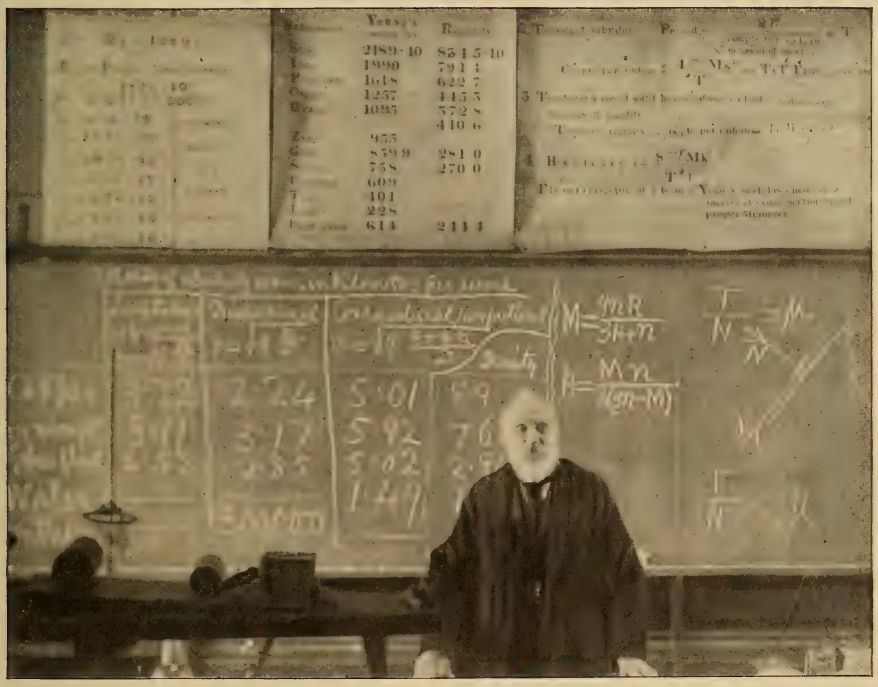
He tests the students' progress by weekly written examinations and by *viva voce* questions, which he passes from bench to bench during the progress of the lecture, following a practice which his father found so successful in teaching. The answering is not always satisfactory, and one morning, when the students were more than usually reticent in their replies, he wrote down on the blackboard the word "aphasia," gave its Greek derivation, and defined it as "a virulent disease common among the students of the natural philosophy class."

The elements of physical astronomy are included in the work of the class and voluntary reading set in it. Christmas vacations he considers a suitable time for reading, and once, to the students' horror, he suggested that during it they should read a certain text-book of astronomy, pointing out that it could be got through at the rate of 50 pages per day. But this was quite to be expected from one to whom every moment is precious and has its own allotted work, and who, as a youth, contrived to master and expound Fourier's "Analytical Theory of Heat" during the brief intervals of a fortnight's travel on the continent.

Eggs, jellies, shoemaker's wax, treacle, all sorts of stuff, are used to illustrate the lectures, and homely experiments are recommended to the student, even the humble teaspoon, "so ill adapted to the purpose for which it is intended," being pressed into the service. In the famous egg experiment he shows how Columbus might have gained his object without breaking the egg. When boiled and set spinning on a table, the egg rises and spins on its end. Unboiled eggs, owing to the fluidity of the interior, do not rise, but if set spinning and then suddenly stopped and immediately released, they continue their motion for a little time. Once, the result of a students' plot, raw

eggs were substituted for the boiled ones, but science could discriminate, and the verdict was unhesitatingly given:—"None of them boiled."

He revels in experiments, and is always at home and serenely happy, whether among forests of organ pipes and tuning forks, or in a sea of bottles and vessels for experiments on capillarity, or surrounded by globes and tops

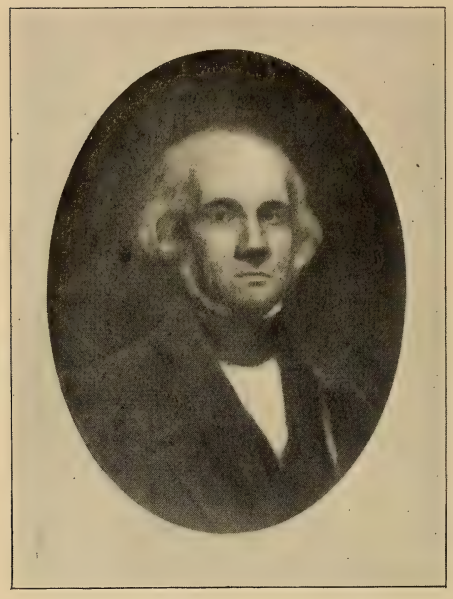


LORD KELVIN ADDRESSING ONE OF HIS CLASSES

to illustrate astronomy. From the close of the prayer, with which, according to the ancient custom, the lecture is opened, until the end of the hour, his body as well as his mind is never at rest. With restless energy he will dart off to the blackboard to illustrate what he has been talking about, his gown streaming out behind him. Loud applause greets his efforts as he wrestles with gyrostats, or works energetically at the brake wheel to illustrate the principle of rope dynamometry.

The appearance of the ballistic pendulum is always hailed with delight by the class, for one of the classical experiments is to be performed,—the determination of the velocity of a bullet by firing it into the heavy wooden bob of the pendulum and noting the displacement produced. Armed with an old Jacob rifle with which, when a volunteer, he used to practice, Lord Kelvin comes to the front of the lecture table, kneels, takes deliberate aim, amid great amusement and excitement, pulls the trigger, and, before the smoke has subsided, is busy at the blackboard with the calculation.

His students are proud of him, admiring his energy and enthusiasm, respecting him for his profound knowledge and his grand work, loving him for his gentle, unassuming nature. On Graduation Day, 1891, after his appointment to the presidency of the Royal Society, they presented him with an illuminated address, amid a scene of the wildest enthusiasm. Many will long remember his claim to their fellowship, —"I have been a student of the University of Glasgow fifty-five years to-



PROFESSOR J. THOMSON, SR.

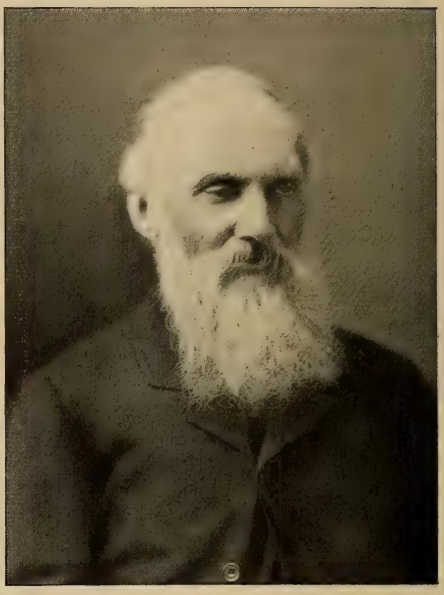


PHOTO BY DOWNEY LONDON

LORD KELVIN IN 1891

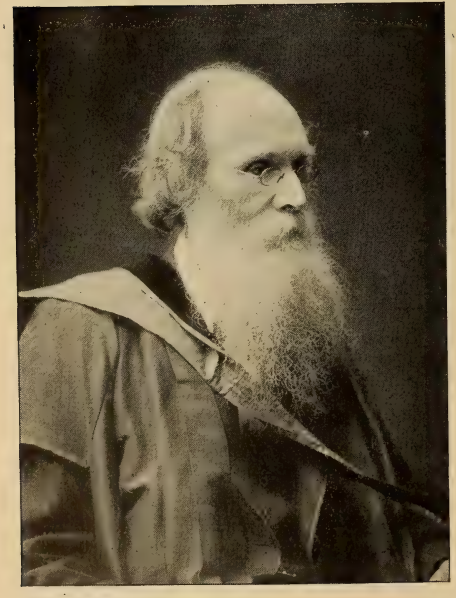


PHOTO BY ANNAN

PROFESSOR JAMES THOMSON, LORD KELVIN'S BROTHER

PHOTO BY MELHUISH, LONDON

DR. JAMES T. BOTTOMLEY, LORD KELVIN'S NEPHEW

day, and I hope to continue a student of the university as long as I live."

They thoroughly enjoy themselves at his "At Homes" for students. There he displays the great interest he takes in everything, even the most apparently trivial. With boyish delight he explains the latest puzzle or scientific toy, and shows lantern slides from which not even the comic element is excluded. On such occasions he is ably seconded by Lady Kelvin, and in this gracious hostess the students recognise one who, behind the scenes, has nobly done her work. How much the world owes to her assiduous care and helpfulness one cannot estimate; but she has proved, in the fullest, widest sense, a helpmate.

Lord Kelvin's energy is wonderful, and undoubtedly his great physical strength is no negligible factor in the amount of work he has done. Unlike many other youthful prodigies, he can look back on a boyhood full of boyish sports, and on a youth when he enjoyed and graduated in the school of sports at Cambridge. In the early days of the volunteer movement he found time to devote to the duties of the service. Curling counted him among its devotees; but an unfortunate accident which befell him in a game, played more than thirty years ago, left him permanently lame and led to the severance of his connection with the volunteers. He humourously explains it:—

"It was this way, you know. I was all right standing at ease and at the manual exercise, but when it came to evolutions, the more the officer commanding ordered us to 'march,' the more I 'halted.' So I resigned."

To-day in his seventy-sixth year he is fresh, vigorous, and working with the energy of youth. But in addition to a superb constitution, time is required for the performance of his multifarious work, teaching, experimenting, writing, lecturing, consulting, speaking in all parts of the country, scrupulously attending to duties, social functions and recreations. A keen politician, a fervid Unionist, he occupies his seat in the House of Lords whenever possible.

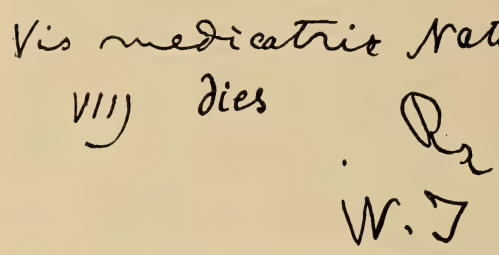
Perhaps mathematics has taught him the value of time infinitesimals. At all events, he integrates them. No moment is lost. Wherever he is, in quiet and peace, in scenes of hurry and bustle and noise, in the railway train or on a yachting cruise, whenever an idea strikes him, out comes one of the famous green note books and he is at once lost in thought and calculation. "Always carry a note-book, compasses, and a ruler," is the "wrinkle" he gives his students.

In his house at the university you breathe an atmosphere of science. Everywhere you see portraits and souvenirs of the scientific giants of the century and their works, amid evidences of his own inventive genius, from the astronomical clock in the hall to the electric light apparatus and original systems of heating and ventilation. In the study you will find an early model of the perfected phonograph, and one of a pair of telephones brought over by Professor Bell to Great Britain. The other, connected to it by a private wire, is in the house of his nephew, James Thomson Bottomley, D. Sc., F. R. S., a few hundred yards away. Dr. Bottomley holds the post of Arnott and Thomson demonstrator in natural philosophy, and represents the Thomson family in the third successive generation that has supplied a teacher to the University of Glasgow. Himself a man of high and varied attainments and wide repute, he has, for more than twenty years, been associated with his uncle's teaching and scientific work, and may justly be considered Lord Kelvin's right-hand man.

A list of titles, degrees, diplomas, and other honours bestowed at different times on Lord Kelvin, would fill rather more than four pages of this magazine. In 1890, as Sir William Thomson, he was elected President of the Royal Society, a post once filled by Newton and now the honour of honours for the scientific men of Great Britain. A year afterwards he was raised to the peerage, with the title Baron Kelvin, of Largs, a distinction which, at the time, was unique in the annals of science. In

1896 he was appointed Knight of the Grand Cross of the Royal Victorian Order.

But his own country is not alone in acknowledging his genius. France has created him Grand Officer of the Legion of Honour; Germany, Knight of the Order pour le Mérite; and Belgium, Commander of the Order of Leopold. Four times he has been president of the Royal Society of Edinburgh, and twice president of the Institution of Electrical Engineers. The British Association, with which he has long been connected and in whose affairs he takes a warm and ceaseless interest, elected him as president of its Edinburgh meeting in 1871. The Institut de France has awarded him the Prix Poncelet, and bestowed on him the almost unique distinctions of Foreign Associate and Arago Medallist. He has been awarded the Copley and Royal Medals of the Royal Society, the Keith Medal of the Royal Society of Edinburgh, and the Helmholtz Medal.



LORD KELVIN'S FIRST MEDICAL PRESCRIPTION

He is an honorary member of most of the important scientific societies in the world. Fourteen universities have conferred on him the degree of Honorary Doctor, of civil law, of laws, of science, of physical science, of philosophy, and of natural philosophy. In 1884 the University of Heidelberg, at its tercentenary celebrations, desiring to confer an honorary degree on him, and finding that the only one at their disposal which he did not already possess was that of Doctor of Medicine, accordingly presented him with that diploma. On the very day on which it arrived his kindly eye noticed the indisposition of his lecture-room assistant, and thereupon he wrote out his first prescription, in proper language and form. Nature was the remedy, and a week the dose.

His possession of the degree of M. D. led to an amusing scene a few years ago when giving evidence in a famous medical electric case. An opposing counsel, desiring to make a point, remarked that he presumed Lord Kelvin's numerous qualifications did not include those of a doctor of medicine; and one may imagine his confusion when Lord Kelvin ingenuously replied that he had received the degree of M. D. from Heidelberg University.

Such honours, conferred on Lord Kelvin, enable one to judge how highly he is everywhere esteemed; but even they fall short of that which was given in 1896, when, from every civilised country, from every corner of the globe, came students, professors and representatives of scientific societies, bearing honours and congratulations, to take part in the celebration of his jubilee as a professor at Glasgow University. Never before had such a distinguished company of scientific men been gathered together, and the enthusiastic and impressive proceedings will long be remembered by those who took part in them. Cables carried congratulatory messages over every ocean, and delivered them to the siphon recorders which were on exhibition with Lord Kelvin's other inventions. It was a stirring and a hopeful scene. Men of all nations, bound by one tie, united to do honour to one man whom they all claimed as brother.

It is difficult to realise that we have among us to-day, active and productive as ever, one who has marched in the van of scientific progress for more than fifty years. To-day, in his seventy-sixth year, he is still young and working with unabated energy and success. Surely we may say of him, as he said of Joule, "It was hard work, early begun and persevered in, and conscientiously carried out; that is the foundation of all great works, whether in literature,

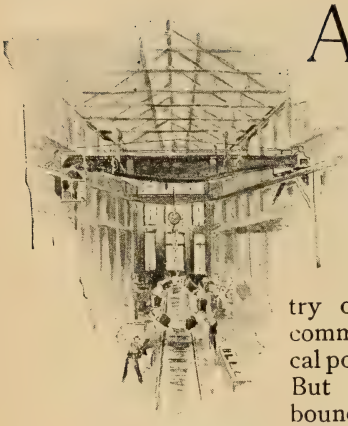
NETHERHALL, LARGS, LORD KELVIN'S COUNTRY SEAT

philosophy or science, or in doing good to the world in any possible way."

In his work there is manifest the genius that has the capacity for taking infinite pains as well as the genius that does great things seemingly without effort. Such an intellect is like the far-seeing telescope which, when reversed, becomes a microscope. Nothing is too large; nothing too small. Everything is subject to scrutiny. Who that has heard of him does not admire his grand work and his tireless genius? Who that knows him does not love his simple, happy nature? Surely we join the cry: —"Long live Lord Kelvin."

ELECTRICITY AS A FACTOR IN MODERN DEVELOPMENT

By Professor R. B. Owens



A SINGLE invention,—the steam-engine,—has made more history in its short life than half the world's rulers. Sprung from the genius of Watt, it has made the country of his birth the commercial and political power of the world. But its influence is bounded by no geographical limit. Everywhere in mill or factory, it makes, or as the motive power of the ocean steamship and express locomotive, it distributes, practically every product that lends comfort and ease to modern life; and, when further we consider the cotton gin and spinning frame, the advances in metallurgy, and the use of metals in building construction, the armoured warship and machine gun, the cylinder press and type machine, the modern railway coach and tram-car, present methods of illumination and sanitation, the electric motor, telegraph and telephone, we begin to appreciate, in part at least, the engineer's work as a factor in modern development.

Not from a material standpoint, however, is the result of his work best seen. The substitution he has effected through hydraulic and thermal machinery, of mechanical for manual labour, by giving leisure for thought and relief from drudgery, has raised the ethical and moral standard of the civilised world. Few, perhaps, adequately appreciate the social influence of power, particularly of electric power, in modern life.

Though far beyond the scope of this paper to discuss in detail the effect of even a fraction of its many applications, the writer would, in this connection, particularly mention electric traction and the use of electrical machinery for general motive power purposes.

ELECTRIC TRACTION

Consider first electric traction. By its introduction not only have the sanitary conditions of cities been improved, and has an immense amount of time for pleasure or business been saved, but healthy country homes have been substituted for the over-crowded tenement.

Rapid transit and cheaper fares enable the artisan and wage earner to escape from the discomforts that formerly were theirs, and to live in healthy surroundings on the outskirts of the town or city where they find employment. No longer must they herd in crowded barracks beside their mill or factory, for at less cost and without encroaching upon their hours of rest or recreation, their home may be six, eight or ten miles from the scene of their labour.

With horses for motive power, this was impossible, both on account of the time wasted and because of the higher cost of transportation by such means. But electric traction is not dangerous at higher speeds than is possible with horses, and the small cost of electric operation permits of low fares being charged.

It may safely be asserted that electric traction, more than any other factor, has transformed the conditions of life in very many cities, and the change has been one wholly tending towards social and moral elevation. To thus remove a large proportion of the working class

from over-crowded areas, and to place them amid wholesome surroundings in a healthy atmosphere, is a task of which the engineer may well be proud.

The effect of rapid transit on urban architecture is also plainly seen. Instead of its being necessary to group dwelling-houses in monotonous rows, like the cattle stalls of a country fair, the modern architect and landscape gardner are allowed freer scope for their respective talents, with the pleasing results already becoming familiar.

Indeed, the day is not far distant when the city "block" for dwelling purposes will be a thing of the past. The very same agencies, natural sources of power, waterfalls and coal-fields, which formerly operated to concentrate population, are now, through improved methods of power transmission and distribution, working in an opposite direction, and, as time goes on, a man's place of living will bear less and less relation to the location of his office or other place of conducting business.

In regard to electric power for industrial purposes, although the writer does not believe that its general introduction will substitute the home workshop for the large factory, the change from older methods of factory driving to the present method of using electric motors has a distinct and elevating influence upon the character of the men employed. The cleanliness, order and neatness which it renders possible are a potent influence for good.

ELECTRIC LIGHTING

Sir Humphrey Davy, with a battery of copper-zinc elements, gave us the electric arc in 1810, by passing a current of electricity between the ends of carbon pencils held a small distance apart in air; but the generation of electricity by chemical means was then, and is still, too expensive for commercial use. It was not until after the discovery of the principle of the dynamo by Henry, in 1830, and Faraday, in 1831, that the way was opened for the general application of the most beautiful and easily managed of all forms of physical energy.

Coupled with the steam-engine and water-wheel, the dynamo converts the solar energy of coal-fields and waterfalls into a subtle and powerful force, whose applications are literally without number. Unaffected by gravity or temperature, capable of indefinite subdivision and highly efficient conversion, and requiring the simplest of all means of conveyance,—a stationary metal conductor,—no limit can be put upon the use of electric power.

In 1870 the dynamo machine might be said to have reached a commercial form, but the problem of electric lighting was not solved until ten years later. Early in 1880 Edison filed an application for a patent on a system of electric lighting involving the use of high-resistance electric lamps arranged in multiple circuit across the terminals of a low-resistance dynamo, solving by this combination the then serious problem of the subdivision, as it was called, of the electric light.

In September, 1882, the Edison Electric Illuminating Company, of New York, started their historic Pearl Street central station at New York to supply current on a commercial scale to the downtown or business districts of the city, and within the next few years many of the problems of central station practice were worked out about this old station.

So rapidly were the advantages of the incandescent lamp appreciated for interior lighting, and of the electric arc for street illumination, that in less than a single generation from fifteen to twenty million incandescents and nearly half a million arcs came into use in a single country,—the United States.

In the early days of the industry, when the problems of insulation and distribution were imperfectly understood, it was necessary to use low electric pressures and to place the central station close to the district to be supplied; but now that we have become familiar with pressures of ten, twenty, thirty, and fourty thousand volts, and the possibilities of alternating currents

for transmission and distribution are better known, the station may be located well outside the limits of the average city, feeding into suitable substations wherever current is required. This means both great economy in the cost of generation, and absence of the familiar smoke nuisance.

The most notable example of this practice of concentrating all generating machines in a single plant at a distance from the districts to be supplied will be available at New York, where the Third Avenue Railway Company are now installing the largest steam-electric plant in existence, to consist of sixteen 6000-horse-power dynamos, having a combined capacity of nearly 100,000 horse-power, the equivalent of more than a million 16-candle power incandescent lamps. The station will be situated on the upper end of Manhattan Island, near the East River, and will distribute current by underground conductors, at a pressure of 10,000 volts, to substations in all parts of the city. From the substations current will be supplied for surface and elevated railways, electric lighting, motors, and other demands.

The two engineering problems that excite most interest to-day are the efficient conversion of the energy of fuel into electric energy, and the conversion of electric energy into light, without accompanying heat. The steam-engine converts only from five to ten per cent. of the chemical energy of coal into mechanical power, while the dynamo converts from ninety to ninety-five per cent. of the mechanical power it receives into electric power.

In point of efficiency the dynamo is practically perfect, but all thermal engines are subject to laws which, under working conditions, sadly limit their efficiency. Therefore, the effort is being constantly made to convert the chemical energy of carbon directly into electric energy, without passing through the form of heat, a process essentially similar to the conversion in the ordinary zinc-copper battery; but, so far, no practical carbon battery has been produced.

The efficiency of the incandescent lamp, though somewhat improved in late years, is still extremely small,—only about three per cent.,—the major portion of the electric power supplied being dissipated as radiant energy of a wave length too great to be appreciated by the eye. Vacuum tube lighting, at high frequencies and high potentials, promises something; but the results so far obtained have not been all that was anticipated. If modern lighting apparatus could be brought to the efficiency of that of the glow-worm and firefly, the consumption of a few tons of coal per hour would light the world.

ELECTRIC POWER

Power distribution by electric motors, though first developed in conjunction with electric lighting, not only now exceeds many times the lighting interest, but it has become one of the largest commercial enterprises of the globe. In 1896 more than a million horse-power in electric motors was employed in America in street railway transportation alone, conveying, by a recent estimate, more than three billion passengers, and earning something like $125,000,000. These same railroads employ an army of 200,000 men, and represent an invested capital of from one to one and a half billions of dollars.

When we further consider the aggregate capacity of the thousands of motors employed in the distribution of power for other than traction purposes,—in machine shops, cotton mills and sugar houses, in printing, pumping, hoisting and ventilating, on modern warships for steering, handling ordnance, and other services, to say nothing of the apparatus used in the transmission of power, as distinct from power distribution,—we begin to form some adequate idea of the influence of this new agent.

Before the invention of the steam-engine, waterfalls were of first importance as sources of power, and usually attracted settlements about them; but after Watt's discovery and Stephenson's application to the locomotive, it was found more convenient to transport the new source of power,—fuel,—to different established centres of popula-

tion, instead of moving the centres of population to the sources of power.

With the advent of electricity, however, not only have water powers acquired a vastly increased value, by reason of the ease with which their energy can be economically transmitted over great distances, but electrical methods of distribution have in some cases actually superseded the railway for fuel energy transference.

The first experiment to reveal the astonishing possibilities of electric power transmission was made in 1891. In that year about 200 horse-power was transmitted over a wire, roughly, one-tenth of an inch in diameter, from Lauffen to Frankfort-on-the-Main, in Germany, a distance of 108 miles, with a total loss in transmission and conversion of less than 30 per cent.

About the same time plans were in preparation for harnessing the mightiest of all Nature's water powers,—Niagara Falls,—and a commission appointed to consider methods, including among other distinguished scientists and engineers, Lord Kelvin, of Glasgow, and Professor Unwin, of London, after carefully considering all known means of power transmission unanimously adopted electricity. To-day about a mile above the Falls 50,000 horse-power is continuously flowing from half a score of huge spinning tops. No feat of modern engineering has been watched with greater interest than this, and none has been more successfully conducted.

The power of Niagara has been estimated at about 7,000,000 horse-power,—greater probably than the physical force the whole human race is capable of continuously exerting. At present about 350,000 horse-power is to be developed on the American and Canadian sides, or about five per cent. of the total power available,—not enough to perceptibly diminish the flow over the Falls. However, should the whole be utilised, leaving the rocky river bed dry and bare, we would but be substituting a wonderful cataract of etheric energy for the splendid flow of gravitational matter so justly famed. Which spectacle would present greater beauty would depend upon the individual.

To those who trace in imagination the course of a beam of sunlight, as it buries itself in the ocean, rises in cloud, and falls again in grateful shower over grain field and vineyard, filling brook and swelling river, and finally tumbling through mighty turbines and silently streaming from the polished slip rings of stately dynamos, bursting again into wholesome sunlight, to brighten the homes of hundreds, the substitution would but be the completion of a full cycle of usefulness and beauty.

The question is often asked, Will electricity eventually supersede the locomotive on the present steam railroads? Careful estimates show no economy of electricity over steam for the handling of heavy freight traffic, where the number of trains operated per day is small; but for passenger service, where trains must be operated at frequent intervals on small headway, the advantage is with electricity, and it is probable that because of the smaller cost, as well as increased speed, many large cities will be connected by through lines in the near future.

It is also of interest to inquire as to the probable limit of economical power transmission by electrical means. In reply to this it may be said that Lord Kelvin, after an inspection of the Niagara plant in 1897, is quoted as placing the limit at about 300 miles.

At Snoqualmie Falls, Washington, U. S. A., there is now being installed a 6000-horse-power plant, to supply power to the cities of Seattle and Tacoma, one 31 and the other 45 miles distant. The pressure used is 25,000 volts. This voltage, though perhaps the highest in commercial use for so large an amount of power, is by no means the limit of practicable electric pressures, smaller amounts of power being transmitted commercially at pressures as high as 40,000 volts, and to distances of 85 miles. Recent experiments show that the leakage losses in a well-constructed transmission line are practically negligible, up to pressures of from 50,000 to 60,000 volts. Beyond

this, however, such losses seem to increase rather rapidly.

THE TELEPHONE AND TELEGRAPH

The principle of the telegraph was discovered by Prof. Joseph Henry, in 1829, and was first practically applied by Morse in America and Wheatstone and Cook in Great Britain. The first telegraph line in America was erected between Baltimore and Washington in 1844, and the first message,—"What hath God wrought,"—is ever recalled with increasing force, as we contemplate the vast network of wire and cable that now forms the nervous system of the commercial and political world.

For a long time the simple Morse system of telegraphy was the only one in general use in America, and similarly the single needle system in Great Britain, but as these became inadequate to the volume of business to be done, other and more rapid systems were developed.

The "duplex" system, by which two messages can be sent in opposite directions at the same time over the same wire, appeared in 1858, but did not come into general use until in the early seventies. Later, in 1878, Edison brought out his "Quadruplex," by which four messages can be simultaneously transmitted over the same wire without interference. Of late, the Delaney "synchronous multiplex" has taken a prominent place; but without doubt the greatest advance that has been made for many years in land telegraphy has occurred in the past year, and is due to Professor Henry A. Rowland, of Baltimore. He has brought out a "multiplex printing telegraph," by which sixteen messages per minute, of twenty words each, may be sent over a single wire by operators skilled only in the use of the typewriter, the messages being automatically recorded, not in cipher, but in ordinary type, at each end of the line. A modification of Professor Rowland's system, adapted to automatic sending, will transmit from 3000 to 4000 words per minute.

But notwithstanding these devices, by which the carrying capacity of a single wire is multiplied many times, efforts are continually being made to do away with wires altogether, and to transmit messages by setting up electro-magnetic waves at different sending points, and using suitable detectors as receivers. At the transmitting station, by means of a key and suitable sending mechanism, a series of electro-magnetic waves are projected into space and travel in all directions with the speed of light. Falling upon a metallic collector connected to a tube containing fine conducting particles in loose contact, the particles are found to cohere and to have an increased electric conductivity. This change in their conductivity is readily used to register a signal. Other forms of detectors or receivers have also been devised. Wireless, or space, telegraphy, as it is sometimes called, though partially successful up to distances of about twenty miles, will not, in its present form, supersede the older methods. It is, however, finding a limited application in Great Britain, particularly in coast signalling, and Mr. W. H. Preece, in a recent address before the Institution of Civil Engineers, stated that a system of his own is now in use by the Post Office and War Departments of the British Government.

The extent to which the telegraph in its ordinary form is used may be roughly gathered by recalling that in the United States there are more than a million miles of telegraph wire, strung on over 200,000 poles, and connected to about 25,000 offices. The number of messages annually transmitted by a single company has already reached some 70,000,000, resulting in a gross income of over 25,000,000 dollars.

The telegraph and cable systems of the British Empire employ, according to recent statistics, about the same length of wire,—1,111,000 miles, and transact a proportional business.

No great advance in cable working has been made since Lord Kelvin devised his mirror galvanometer and siphon recorder, except the application of duplex working, by which the capacity of cables has been practically doubled; but a great number of improve-

ments in detail have been effected and many new cables have been laid, until now about 150,000 miles of ocean cable are in use, costing, roughly, about £30,000,000, and requiring a fleet of over twenty ocean-going vessels to keep them in repair.

Bell obtained his fundamental telephone patent in 1876, and a number of important improvements were made shortly after. The first Bell instrument was used both as a receiver and transmitter, but the carbon transmitter and induction coil made their appearance within the next year. Since then a vast amount of work has been done in perfecting details, and now telephonic communication is daily carried on between points from 1000 to 1800 miles apart with perfect clearness.

In the United States there are considerably over a million telephone instruments in daily use, and each day more than three million connections are made.

In Great Britain about 150,000 miles of telephone wire are in use, and the number of messages per year has reached something over eighty million.

OTHER APPLICATIONS

The most marked feature of electrical development in the past year has been the astonishing growth of the electric vehicle business. Cleanliness, increased speed, and the easing of the congested traffic conditions in crowded business districts are obvious results; but the betterment of country roads may be hoped for even to a greater extent from the use of the automobile than from the bicycle. The old days of post roads and country inns will be revived; but electricity, instead of horses, will be the motive power. Indeed, a company has recently been organised in Paris to carry out this very idea.

The applications of electricity in electro-chemical processes and in the refining of metals is also most marked. In 1897 the output of German electrolytic alkali works alone was 20,000 tons, and in the past year it is estimated that more than 300,000,000 pounds of copper were electrolytically refined. About 8,000,000 pounds of aluminium are also annually produced in the same manner, to say nothing of the various products of the electric furnace.

In hundreds of other ways electricity is playing a similar part. In agriculture, electrical methods of stimulating plant growth have passed the experimental stage; in medical practice it has become indispensable; in domestic life the electric call-bell, chafing dish, and fan motor bring a measure of comfort even to bachelor quarters. Indeed, no bounds can be placed upon this spirit of the nineteenth century, that comes

> "To answer our best pleasure; be't to fly,
> To swim, to dive into the fire, to ride
> On the curl'd clouds."

Current Topics

CONSOLIDATION is to-day the ruling passion in industrial enterprise. In common with other undertakings the electric railway has not escaped it, and the process of gathering in half a dozen or even more establishments, bringing them under practically one management, and attempting to control them from one central point of intelligence and financial power, has been going on apace, especially in the United States, where financial engineering has probably never before been at a higher pitch of interest. With this process, however, have come legitimate engineering conditions which have been met only in part,—conditions which, in the interests of the highest money returns for the capital invested, or to be further invested, in the several lines of one system of such railways, practically demand centralisation as well of operating power; that is to say, of steam or water and electric power, and the consequent reduction in operating, or power house, expenses. Where several roads have undergone consolidation we find, as a rule, as many power houses as there were originally independent roads, sometimes, too, located in as many closely grouped townships, and a natural tendency is to retain these and let them continue to supply power, each to its own line. With the economics of electric power distribution, however, shaped as they have been by the possibilities of high-voltage transmission, the rational course to follow would seem to be the abandonment of the several power stations for one station, large enough to satisfy the combined demands for power, and located at the most favourable point for distributing the power and receiving supplies. With a tide-water station coal would be available at a relatively low price, condensing water could be had at next to no cost, and the money investment for ground space for the station itself might in most cases be brought down to a minimum. Alternating current at a high tension could be supplied from such a station, under the most economical conditions possible, to judiciously located rotary transformer substations, and from these direct current at the usual voltage could be delivered to the several railway circuits. Whether the cost of operating this single station would be sufficiently below the united costs of operation of the several stations to warrant abandoning them and building and equipping the new large plant is, of course, the deciding factor in the problem, and a variable one as well for each new set of conditions. In several recent cases, however, it has been demonstrated that the large single plant would lead to more

profitable returns. Such high-voltage alternating current distribution and rotary transformer substations figure prominently in the latest advances in electric railway engineering.

NOTHING within the past year or two has directed more attention the world over to the capacity for rapid and good work in American engineering establishments than the recent award of the contract for a bridge over the Atbara River, a tributary to the Nile, in the Soudan, to an American firm of bridge builders. The bridge was needed most urgently for railroad use in connection with Sir Herbert Kitchener's famous military operations; indeed, time was of the first importance, and in this respect the American builders distanced all other bidders, guaranteeing to deliver the whole bridge of seven spans in seven weeks, while the earliest delivery that could be obtained from any of the British firms was for two of the spans in six months. Why American builders should, in this instance, have led the world and have crowded British firms out of a territory which they might well have considered peculiarly their own, is an interesting question. Improvements in methods, the introduction of time and labour-saving devices, with the incidental reduction of costs, furnish a ready answer, and it is particularly interesting to note that as not the least of these improvements electrical conveniences have been cited. Electrically-driven shop tools, heavy ones as well as light ones, have eliminated many difficulties of operation, and electric cranes have greatly simplified the handling of heavy pieces. The principle of portability in the tools, moreover, has been applied to the widest possible extent, and, in itself, has contributed almost as much as any one other thing to that rapidity and excellence of output for which American shops have become noted.

A PLEA for a system of standards for direct-connected generating sets was made by Mr. J. B. Stanwood, in a paper read at the recent meeting of the American Society of Mechanical Engineers, and in its essentials should appeal to every builder of engines and dynamos. With the introduction of an electrical generator, attached to, and directly driven by, the main shaft of a steam-engine, a new machine has been evolved which has brought with it a new problem, frequently requiring special design and construction. The determination of the sizes and speeds of such generators, as Mr. Stanwood puts the matter, is usually in the hands of some one who is not in touch with either the engine builder or the generator builder. He may be a consulting electrical or mechanical engineer, an architect, a salesman, an agent, or some person presumably skilled in deciding upon the necessary machinery to satisfy certain conditions. If, fortunately, there existed a list of capacities and speeds for electrical generators that was recommended by proper authorities, this list would gradually be used by such persons in securing and specifying the machine to be employed. As it now is, any odd size and speed may be selected by them; as, for instance, a 45-kilowatt generator to be operated at 210 revolutions, as was specified, in one case, almost at random.

IF, for such a generating set bids are taken, then the engine and dynamo contractors who are unlucky enough to secure the order must design a special outfit. Perhaps this is the first time that A's engine has ever been sold to drive one of B's generators, and a new size of engine may have to be built, or *vice versa;* at any rate, a correspondence ensues, with an interchange of drawings for a new pattern of sub-base which has to be made. It may happen that the engine shaft has to be enlarged to fit the armature, or the latter has to be changed to fit the shaft. Later, the shaft has to be shipped to the dynamo shop to be pressed into the armature, or the armature sent several hundred miles to be fitted to the shaft. In all

this it is fortunate if mistakes or misfits do not occur. When the combined plant is ready for installation, the engine erector has to co-operate with the electrical erector; usually one waits for the other a few days, under expense, doing nothing. Then begins the adjustment of the engine's speed to suit the generator's speed, which may be slightly fast or slow, as the case may be; the governor, too, may be out in a similar way. All told, these operations form a complicated and cumbersome system, which would be greatly ameliorated if there existed recognised and approved standards for a very few and simple conditions. With such standards a fewer number of engines with their sub bases and generators would be required. These, in the marketable sizes, could be carried in stock ready for any combination, thereby permitting manufacturers to avail themselves of multiple production, so great a factor in reducing costs, improving quality, and facilitating delivery.

In the same paper Mr. Stanwood emphasises also the point which has become recognised everywhere that an important factor in America's industrial progress has been the extended application of standards. There are standard dimensions for materials; standard sizes, parts, and capacities of machines; standard gauges for close measurements; standard systems of inspection and testing, and others. These different forms or methods of standardisation have usually originated or developed in commercial and manufacturing activities, independent of any governmental instigation or control. This principle of standards, as carried out in individual American shops and factories, has developed the well-known "interchangeable system" of construction, which, by forcing attention and care upon little things has further specialised operations and has stimulated the development of special machines to perform these operations to the end that the cost of production has been greatly reduced. Such standardisation inside and outside of the shops also aids rapidity of production, inasmuch as standard material can be kept in stock to form standard parts or to complete standard machines, apparatus, or goods, all before these are even ordered. These results,—cheap production and prompt delivery,—in connection with a high grade of product, to which these methods contribute, are most powerful factors for securing and maintaining foreign trade. Such influences are particularly active in America to-day.

From a mechanical engineering point of view alone it is interesting to note that Rear-Admiral Makaroff, of the Russian Navy, whose name has latterly become most familiar through his connection with the building of two powerful ice-breaking steamships for the Russian Government, has made the novel suggestion to reach the North Pole by means of such vessels. The 3000 H. P. American ice-breaker *Ste. Marie*, of which an illustration appears elsewhere in this issue, has been credited with sailing with comparative ease through ice 2½ feet thick and with breaking down ice walls as high as 15 feet. With this performance in mind, and taking into account that, according to Nansen, the ice-walls in the Arctic basin seldom attain the height of 25 feet, and that the polar sea is free from ice over, at least, one-third of its surface, while all the ice is weakened in summer by thawing, and especially by interior canals due to accumulations of salt, and by crevices, Admiral Makaroff concludes, so we are told in *Nature*, that an ice-breaking steamer of 20,000 horse-power would overcome all the difficulties which polar ice may oppose to her progress. The distance between the latitude of 78° N. to the Pole being 720 miles, he calculates the various speeds at which such a steamer could make her way through ice of various thicknesses from four to seven feet, and he finds that the total distance could be covered in twelve days. Moreover, instead of one ice-breaker of 20,000 horse-power, it would

be advantageous to have two such vessels of 10,000 horse-power each, it having lately been proved by experiment in Russia that two ice-breakers, placed one behind the other, and the rear one pushing the front one by means of a special wooden frame, act as effectively as one single ice-breaker of a double power. Admiral Makaroff's proposal, and there is nothing more at present, is, therefore, to build for the intended purpose two special ice-breakers of 6000 tons and 10,000 horse-power each.

THE naval battle off Santiago, last year, during the Spanish-American war, was the occasion on which the secondary batteries of war vessels came to the front in the popular mind. Lieutenant F. K. Hill, who had command of the secondary battery on the upper deck of the U. S. battleship *Iowa* during that engagement, however, maintains, in the Proceedings of the United States Naval Institute, that if this action be carefully analysed the secondary battery will not be so important as we are led to believe from common report. The secondary batteries of the large ships did what they were called on to do in the case of the torpedo destroyers, and that was legitimate and complete work in their line. The secondary batteries of the large ships also did most of the damage to the four Spanish armoured cruisers. In Lieutenant Hill's opinion, however, it does not follow from this that the main batteries should be reduced in either number or size. To begin with, the Spanish ships were whipped so quickly that there was no time to develop the ultimate fighting strength of the American vessels. Besides, the Spanish ships were loaded up with wood, and their destruction was due secondarily to this fact, as fire was an important feature in their destruction. Finally, the Spanish gunners did no good shooting, so that the service of the American secondary battery guns was never interfered with materially. For these reasons Lieutenant Hill thinks that if the battle had been between two fleets of battleships, practically non-inflammable, with good gunners on both sides, the first part of the action would have seen the mutual destruction of the secondary batteries and crews, and the final test would have been between the heavy guns and the armour.

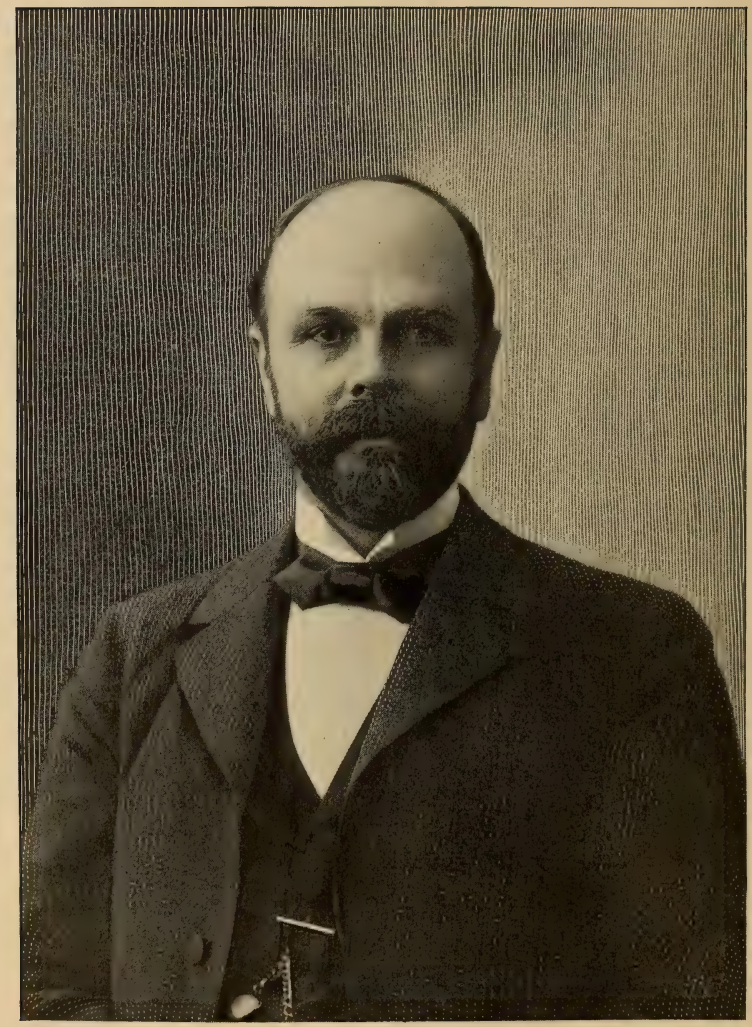
IT is an old adage that "Nothing risk, nothing gain." This maxim might well be read, "With no great risk there is no great gain." But the "risk" is a relative matter and not an absolute one. That which in the hands of one person would inevitably fail, may, in the hands of another, be successful. Not infrequently an enterprise which from one view-point has already failed has, in fact, merely reached the first toll-gate on the highway to success. In a paper read a short time ago before the American Association of Inventors and Manufacturers, Mr. Francis H. Richards made the point that the probability of success is measured by the environment and the resources available. One person, examining a certain enterprise and finding the risk of too hazardous a nature to warrant his attention, may very properly decide the enterprise to be impracticable, or, as to himself, impossible of accomplishment. This decision under the circumstances does not in the least indicate that, from the standpoint and experience of some one else, the same enterprise cannot be safely undertaken and effectually carried on to a successful conclusion. The real question, therefore, is not so much whether a risk exists, but what relation the existing risks and uncertainties bear to the ways and means that are available for overcoming them.

THIS principle is well illustrated by many of those newer institutions which are classed among the "necessaries" of modern life. Consider, for instance, the many facilities which are now accomplished facts but which not so very long ago, as history is measured, could not have been produced by any one anywhere in the world. The electrical propulsion of cars, for instance, is an ac-

complished fact of almost immeasurable practical importance, and yet only a century ago such an achievement was not only undreamed of, but was literally impossible of accomplishment under the conditions then existing. The same is true of the steamship, the modern locomotive, the ice-making machine, the reaper, the telegraph and ocean cable, the telephone, the newspaper, the modern postal system, and of many other instrumentalities which have come to be considered necessary not only to the progress, but even to the sustenance of the race. The times and circumstances, therefore, rather than the risks and the difficulties involved, determine, broadly speaking, the feasibility at any given time and place of every undertaking which is "possible" within the limits of natural laws.

SETTING back a bulged furnace crown in a boiler is generally about as hot and dirty a job as any one would care to tackle. The usual way is to apply a fire below the bulge and then to force it by a blast led from a rivet fire bellows. After the distorted plate has been sufficiently heated, the fire is withdrawn, and a jack is applied to force the bulge back This must be done quickly or else the bulge will have cooled down so much that it will not yield to this treatment. In the limited room for working, it is always an awkward and unpleasant job. In removing the fire it often gets spilled about, and the necessary packing to keep it up to the bulge has also to be cleared out of the furnace, and during the time this is being done the heated part is rapidly cooling. For reheating, the fire must again be packed up against the bulge, and the cycle of operations repeated till the furnace is sufficiently restored to shape. The whole of the work has invariably to be performed at the place where the boiler is worked, with what appliances can be most conveniently found, often by workmen who have had no experience with this class of work.

WHAT would appear to be a decidedly better way of doing the work was recently proposed in *Engineering* by a boiler inspector. According to this, a wrought iron pipe, about 1 inch in diameter, is fitted to the bottom of a wrought iron bucket. The end which passes a short distance through is plugged up, the upper part inside the bucket is perforated by a slot or several holes, and the bucket is lined with fireclay. A cross handle to steady the whole is clipped on near the other end of the pipe; that end is connected, preferably by a hose pipe, with the rivet fire bellows. The fire is kindled and properly started before inserting in the furnace. A suitable crossbar with a notch in it is inserted in the furnace tube. The fire can be quickly placed in position under the bulge, and, by grasping the cross handle and the end of the tube, can be rapidly manipulated, as required. It can be quickly withdrawn and laid down well back from the boiler front, so as to be out of the way, and the jack applied to the bulge with the minimum loss of time. A 15 to 20-ton hydraulic jack is the best to use. A small piece of ½-inch or ⅝-inch plate, heated to redness and bent to the circle of the furnace, should be put on the top of the jack to prevent it from cooling and marking the furnace plate. A larger plate, bent to the circle of the furnace, should be placed below the jack to distribute the stress. If any packing is required to bring the jack against the bulge, a single block of good hard wood of suitable thickness should be used. The bulge should be pressed back by the jack; at the same time a little judicious flogging on the water side will make it go back easier. After the furnace has been restored as near as practicable to original shape, the parts that have been set back should be heated to a dull red to remove any local stresses that may have been set up in the plates, and as the fire can be easily shifted about to any desired part of the furnace, this can be easily done.



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W. R. Warner

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CASSIER'S MAGAZINE

VOL. XVI JULY, 1899 No. 3

THE STRENGTH OF THE BRITISH NAVY

By Archibald S. Hurd

WHAT does the navy represent as a national asset? The question should interest all who pay the Queen's taxes; and who does not pay, directly or indirectly, on his income, on tobacco, tea, beer, spirits or property? Every man may feel that he has some share in our all-powerful navy, which comprises 489 ships, large and small, from great armoured battleships of 15,000 tons to little, toy-like torpedo-boats of only 20 or 30 tons displacement. It is no small matter for satisfaction that no other two nations possess a fleet to equal this, the result of many years' sacrifice on the part of the taxpayers. Of how much we devote to defensive purposes, the man in the street has only a vague idea. Last year the naval and military votes

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THE BRITISH IRONCLAD "WARRIOR," 1859

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H. M. TWIN-SCREW BATTLESHIP "RENOWN." LENGTH, 380 FEET. BREADTH, 72 FEET. DISPLACEMENT, 12,350 TONS. I. H. P., 12,000.
THE MOST EXPENSIVE AND LUXURIOUSLY EQUIPPED SHIP IN THE BRITISH NAVY

for the defence of the empire amounted to over fifty million pounds.

There is one satisfaction in the money that the navy swallows up,—and this year it amounts to £28,000,000,—when it has all been spent we have something to show for it in battleships, cruisers and torpedo craft, besides dockyards, coaling stations in every quarter of the globe, and a force of over 110,000 officers and men and well-equipped training schools and barracks. These large sums annually set aside for the defence of our own hearths and those of our kith and kin across the seas and for the protection of our huge commerce, are the insurance premiums that we pay as a nation for our safety, just as an individual insures his life against accident or death, or his property against burglars or fire. But there is this difference between the individual and the nation,—the business man has nothing tangible for his yearly premiums, but we can point to the navy, with its hundreds of ships and its thousands of officers and men, and behind the navy, ready at any moment to support it, are the half a million men of the army and auxiliary forces.

Our first line of defence is the navy. Every one now recognises that sea power is political and commercial power. At the beginning of the century the British Navy was worth only ten millions, and it was with such a fleet that Nelson won his great victories,—the Nile, Copenhagen, and Trafalgar. It was stated some years ago that it was the ships of Nelson that won the battle of Waterloo, and only a few believed it. Now this statement is the ruling principle upon which the defence of the empire is organised.

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H. M. TWIN-SCREW BATTLESHIP "COLOSSUS." LENGTH, 325 FEET. BREADTH, 68 FEET. DISPLACEMENT, 2420 TONS. I. H. P., 7500

As the empire and British commerce have grown, and as France, Russia and Germany have added to their navies, Great Britain has strengthened hers. From 1869 to 1885 we spent on an average only one and a half millions sterling on new ships; since then the average has risen to four and a half millions, and this year the Admiralty are spending £9,257,000 on entirely

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H. M. TWIN-SCREW BATTLESHIP "RODNEY." LENGTH, 325 FEET. BREADTH, 68 FEET. DISPLACEMENT, 10,300 TONS. I. H. P., 11,500

new war vessels. This sum includes the proportion of establishment changes that belong to this new construction, but it does not take any account of £1,608,139 that are being devoted to repairs and alterations to old vessels. We are devoting twice as much money to the navy as any other nation. Other powers boast of huge armies; we rely on a strong navy and a comparatively small army.

It is an astounding fact that £60,000,000 have been laid out in new British warships during the past eleven years, and this spring this huge amount was increased by £9,257,603. These are appalling figures, but they reveal the expenditure in only one department of the Admiralty. The total amount devoted to the navy during the twelve years which ended last March aggregates nearly £173,000,000. In other words, we have spent on the navy during this period a sum equal to over a quarter of the national debt. This is the sum total of our national insurance premiums during this period on account of the navy alone. The army has cost more than as much again.

The result of this self-sacrifice by the nation at large is that British warships are flying the white ensign in all the world's seas, and in every sea Great Britain has a stronger naval force than any other power, except in Chinese waters.

We have a great burden in the national debt; but in the navy we have a splendid asset, though it is seldom, or never, regarded in this light. Those who ever think of our ships from this standpoint would probably be quite unable to state what wealth the navy does represent. The writer has himself put the question to naval officers, and it has been amusing to note the variety of answers. One told him that he thought the navy was worth £300,000,000, and some gave even higher figures; none of the estimates was even approximately accurate. It is imagined that because the British Navy is the greatest in the world and costs so many millions a year, it must represent fabulous wealth.

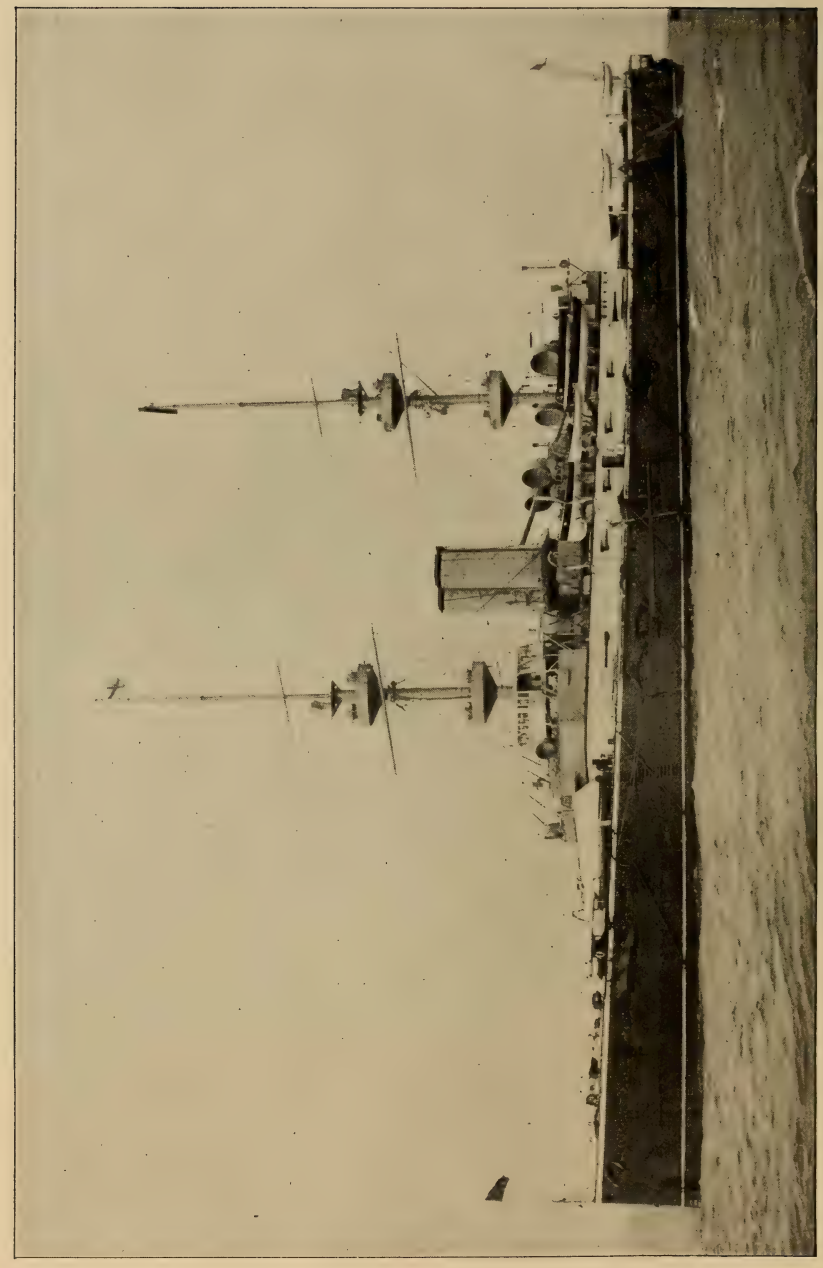
One fact is often overlooked,—that the new ships built each year represent, as a rule, less than a third of the total sum voted by Parliament for the navy, and that ships become obsolete and of no use and are sold for a mere song. It is usually forgotten, even by the swarm of naval critics who watch every action of the Admiralty, that every new ship which is a real addition to the fleet and does not merely replace an old vessel, means either that the total votes for the navy in the future must be increased to provide for its maintenance and the pay of its crew, or a reduced sum must be laid out in fresh construction.

The completion of the cruiser *Powerful* has meant that the Admiralty have to put aside in future years a certain large sum for her maintenance and repair, besides making the necessary financial arrangements for the pay and messing of her crew of 894 officers and men, which swallow up over £70,000 a year, and for the coal required to feed her 48 boilers. This all is additional expense, for the vessel is a real addition to the fleet and not a modern substitute for an antiquated ship.

This process of adding to the maintenance cost of the fleet must operate every time an addition is made, while, at the same time, fresh shipbuilding is going on. This is the explanation of the fact that the total navy votes increase apparently out of proportion to the number of new ships laid down. If this is borne in mind, it will be understood why, despite the vast sums expended on the fleet, the actual value of the navy as a national asset is not greater.

To-day we have a fleet of 489 ships of various classes, with a total displacement of about 1,500,000 tons, excluding those which have been ordered, but have not yet been begun, and the hundred and one old ships that are used as store ships, training ships and in other ways. Of this great fleet nearly 200 of the most efficient and powerful vessels have been built during the past eleven years and have cost £60,000,000. The backbone of the navy is the leviathan battleships, constructed during the past seven years.

We are now building six additional



H. M. TWIN-SCREW BATTLESHIP "MAJESTIC." DISPLACEMENT, 14,900 TONS. I. H. P., 10,000. SPEED, 17½ KNOTS

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H. M. S. 'ANSON.' LENGTH, 330 FEET. BREADTH, 68 FEET 6 INCHES. DISPLACEMENT 10,600 TONS. I. H. P. 11,500. TWIN-SCREWS

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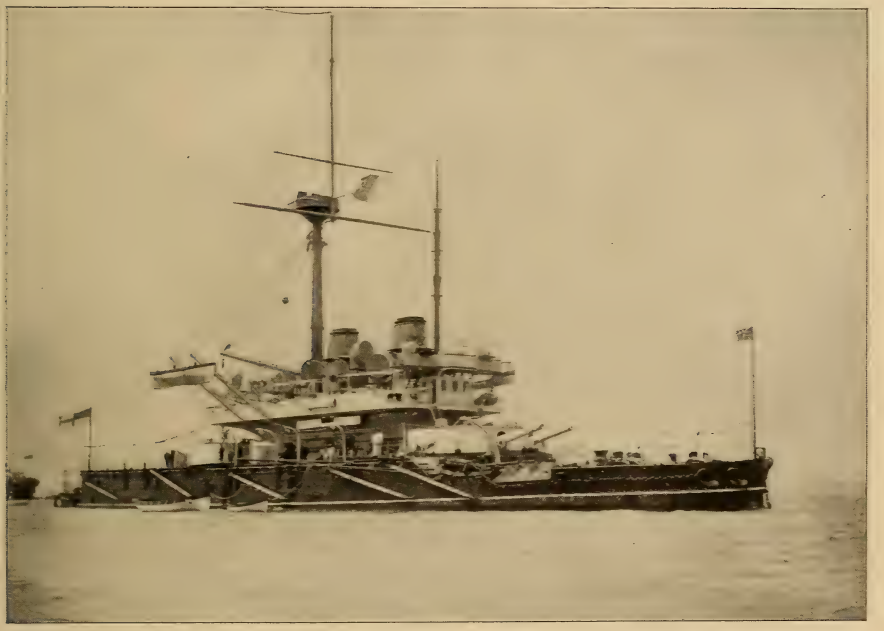
H. M. BATTLESHIP "BENBOW." LENGTH, 330 FEET. BREADTH, 68 FEET 6 INCHES. DISPLACEMENT, 10,600 TONS. I. H. P., 11,500. TWIN-SCREWS

monsters of 15,000 tons, which will cost slightly over a million each, and are known as the *Formidable*, *Irresistible*, *Implacable*, *London*, *Bulwark* and *Venerable*. They will rank with the largest armoured ships in the world, and, despite their coats of 2900 tons of armour, will travel at a speed of over 18 knots, which is equal to 20¾ land miles an hour,—about twice the speed of an ordinary bicyclist. We also have fifteen millions sterling invested in the sive and luxuriously fitted warship in the navy, which is now flying the flag of Vice-Admiral Sir John Fisher on the North American station. Though her displacement is only 12,350 tons,—550 tons less than the *Majestic*,—she has cost the nation a million sterling to build. There are also eight vessels similar to the battleship *Royal Sovereign* with a displacement of 14,150 tons. They stand for seven and a half million pounds and form a most deadly group,



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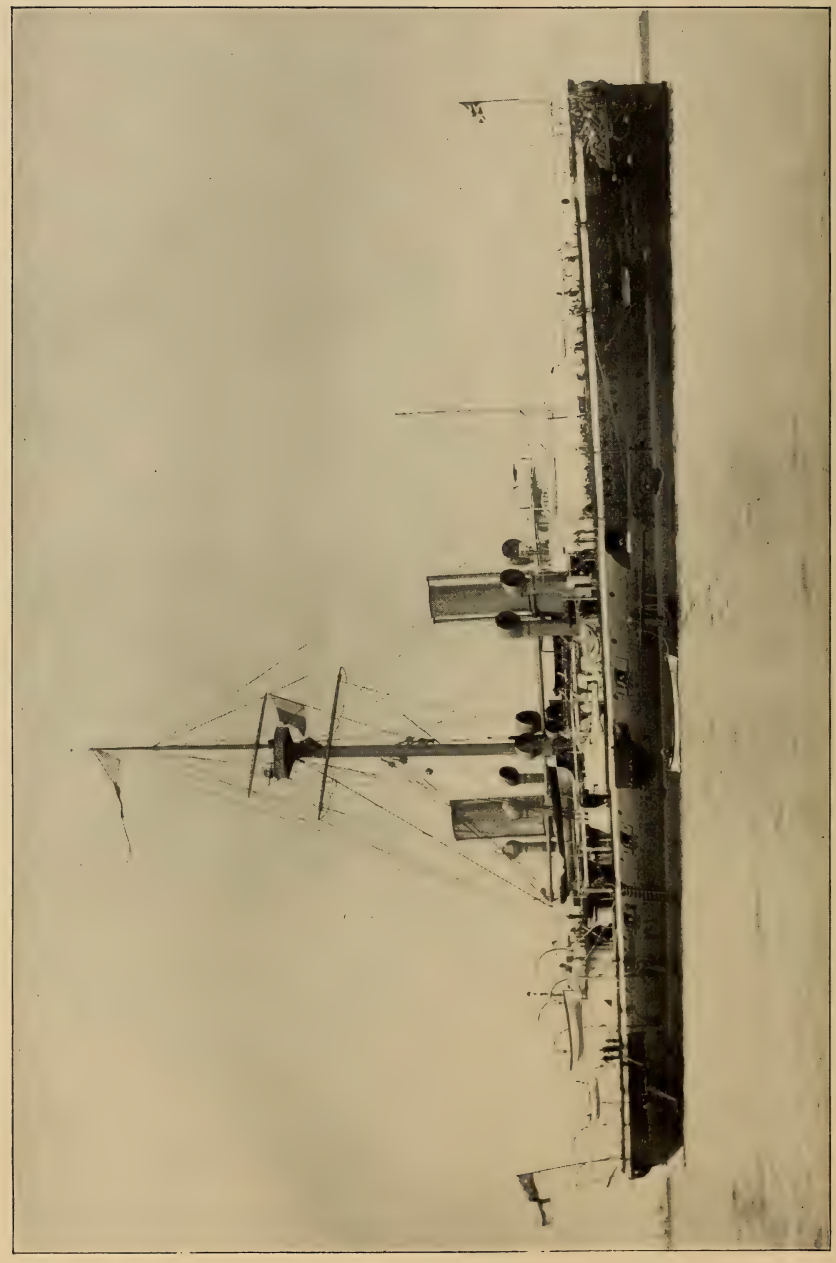
H. M. BATTLESHIP "THUNDERER." LENGTH, 285 FEET. BREADTH, 62 FEET. DISPLACEMENT, 9330 TONS. I. H. P., 7000. TWIN-SCREWS

fifteen vessels of the *Majestic* and *Canopus* classes, and the latter, despite their huge bulk,—each ship displaces 12,950 tons,—will steam at a speed of 18¼ knots when ready for sea. The offensive powers of these vessels are gigantic. During five minutes' firing from her main armament the *Majestic* belches forth nine tons of metal, and the whole twenty-one monster ironclads, if they were to be concentrated in united action, could throw 190 tons of metal every five minutes from their big guns.

To this fleet of new battleships must be added the *Renown*, the most expen- mounting 113 big guns. Passing over two solitary ships of a distinctive type, the *Barfleur* and *Centurion*, and also the *Nile* and *Trafalgar*, which represent three and a quarter millions, there remain the six important battleships which perpetuate the valour of famous admirals, the *Benbow*, *Collingwood*, *Howe*, *Rodney*, *Anson* and *Camperdown*. These, and the battleships *Colossus*, *Edinburgh*, *Thunderer* and *Devastation*, cost the country nearly eight millions sterling.

This exhausts the great ironclads which belong to " classes," and there



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H. M. TWIN-SCREW CRUISER "WARSPITE." LENGTH, 315 FEET. BREADTH, 62 FEET. DISPLACEMENT, 8,400 TONS. I. H. P., 10,000

remain twenty other vessels, four of which, the *Sans Pareil*, *Bellerophon*, *Conqueror* and *Hero*, though comparatively old, are well armed and rank as up-to-date fighting machines. These four vessels cost slightly over two million pounds. There are still sixteen vessels to be taken into account, and they are famous in their way because they are partly armed with old muzzle-loading guns,—the writer refers to the *Ajax*, *Temeraire*, *Inflexible*, *Superb*, *Triumph*, *Alexandra*, *Dreadnought*, *Neptune*, *Sultan*, *Iron Duke*, *Monarch* and *Hercules*, and other vessels which may be said to represent the old navy of eleven or twelve years ago. They are, of course, iron and steel ships and form a reserve, on the value of which, however, no two experts agree. But whatever their fighting strength, they swell the wealth of the navy by nearly eight million pounds.

These are the 64 line-of-battle ships of Great Britain, the backbone of the navy, and they represent no less a sum than £52,000,000 of British wealth. From the fact that when all these floating fortresses are on active service they accommodate over 50,000 officers and men, and mount no less than 2671 guns, some idea may be gained of their great size and of the destruction which they could work, even if they were unsupported by any other vessels of the British fleet.

Of cruisers of all sorts and shapes and sizes, Great Britain can boast more than any probable combination of enemies. They are the eyes of a fleet, the scouts that can sweep the seas, keeping open the highways of commerce and protecting the merchant ships. To a nation with gigantic dealings with all the world, these vessels are of the utmost importance. It is a matter of satisfaction and pride that we have as many as 157 cruisers, some new, some old,—as old as 30 years,—yet doing useful service.

It is curious, however, that the British Navy numbers only thirteen modern armoured cruisers, considering their comparative cheapness. The *Warspite* and *Imperieuse*, vessels of 8400 tons displacement, with powerful armaments and a protection of 10 inches of compound armour, cost only about £1,200,000; while the seven smaller cruisers, *Aurora*, *Australia*, *Galatea*, *Immortalite*, *Narcissus*, *Orlando* and *Undaunted*, which are also provided with thick armour, cost only twice as much to build and arm; that is, £2,400,000.

The next biggest class of cruisers, known as "protected cruisers," is a compromise between heavily armoured vessels, like the *Warspite* and *Aurora*, and the vessels with no armour at all. Of these "go-betweens," we possess 117 thoroughly useful and well-armed ships, on which the country has spent twenty-nine million pounds. Among these ships are included those leviathans, the *Powerful* and *Terrible*, which were built to steam at the rate of 22 knots an hour, but have not done so, unfortunately, since they were completed for sea. They cost slightly over a million and a half, while two ships of the *Majestic* type aggregate two million sterling.

Battleships are the luxuries of very rich peoples, and make comparatively little show alongside the cruisers of an equivalent cost. For the price of a *Majestic*, one could buy seven ships similar to the *Pelorus*, a third-class cruiser, 265 feet long, with a displacement of 2135 tons, a deck of steel 2 inches thick and an armament of eight 25-pounder and eight 3 pounder quick-firing guns, besides three Maxims and two torpedo tubes. Handy little vessels these, and awkward to meet in an ocean highway, and yet they are ridiculously and insignificantly cheap when compared with other ships.

If there were an exchange and mart for warships, we could change a *Majestic* for four cruisers like the *Arrogant*, *Furious*, *Gladiator* and *Vindictive*, each of which displaces 5750 tons of water, and has a deck protection of nickel steel and 21 guns of various sizes, besides submerged tubes enabling two torpedoes to be discharged at once, if necessary; or, we might receive four cruisers like the *Astræa*, with a maximum speed of 20 knots, with good protection, and capable of steaming 7000

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H. M. THIRD-CLASS CRUISER "PELORUS"

miles without re-coaling. The point of these comparisons is that battleships are far more costly than cruising vessels because of the expense of their armour. The armour, gun mountings and torpedo fittings of a single ship like the *Majestic* cost about £320,000, so that the thirty-one vessels of the *Formidable*, *Majestic* and *Canopus* types cost about six and three-quarter million pounds on these accounts alone.

Fortunately, we have only sixteen cruisers "unprotected," of which the most that can be said is that they are a lot for the money. Four of them, moreover, carry antique guns. Any millionaire about to settle on a desert island and anxious to build a navy for his protection, could provide himself with replicas of these sixteen cruisers, complete and ready for sea, at two and a quarter million pounds, which is surely cheap enough for sixteen real fighting ships.

Muzzle-loading guns are often compared with breech-loaders and quick-firers, and it may be useful to illustrate the advantage of the latter types. The following figures illustrate the destruction that is dealt out by the latter.

Diameter of Bore.	Weight of Projectile.	No. of Shots Fired per Minute.
6 in. (7 tons)	100 lbs.	7
4.7 in. (2 tons)	50 "	10
12 pounder	12 "	20
6 "	6 "	25
3 "	3 "	30

The 6-inch and 4.7-inch guns are the largest guns on most cruisers and the smaller ones on battleships. The machine guns carried on all warships fire from 620 to 670 shots a minute, or 10 or 11 a second.

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H. M. BATTLESHIP "DEVASTATION." LENGTH, 285 FEET. BREADTH, 62 FEET. DISPLACEMENT, 9330 TONS. I. H. P., 7000

The fleet includes eleven other cruisers besides those already mentioned,—old ships armed with muzzle-loading guns,—which look imposing, but are of little account in these days. These eleven ships include nine old armoured battleships which have descended to the cruiser class in their old age. The most venerable of these ships, which the Admiralty still regard as effective, is the *Warrior*, which was built at Blackwall in 1860,—the first ironclad

ever constructed, and a relic of the early lessons in battleship building which our naval constructors learnt from the Crimean War. These nine vessels are worth comparatively little, but they cost the country, in the first instance, about four million pounds. In the same "rotten row" may be placed the two old cruisers, *Constance* and *Carysfoot*, which, with muzzle-loading guns and all, cost £250,000.

We have now run over all the 157 cruisers, the scouts of the British Navy, which are the equivalent of forty-two millions six hundred golden sovereigns, gathered from the nation by the energetic tax and customs collectors. The remainder of the fleet consists of coast defence vessels of small dimensions, torpedo vessels, torpedo-boats and destroyers. There are fifteen coast defence ships; but although they cost upwards of three million pounds, they are of little account, twelve of them having old-fashioned guns. The 35 torpedo vessels are useful in their way, and probably cheap at £2,300,000.

Lastly, reckoning must be taken of our wonderful fleet of torpedo-boats and destroyers,—the envy of the world. They number 194 vessels. Of this total, 120 are destroyers, all of which have been built during the past six years, and there are more to follow. They range in speed from 26 to 33 knots. When it is remembered that 33 knots are equal to 38 land miles an hour, it will be understood what marvels in construction these little vessels are. The latest and swiftest, among them, though she has a displacement of only 350 tons, has engines which develop almost the same indicated horse-power as the leviathan battleship *Renown*, which has more than thirty-five times her displacement. In spite of their small size, these little ships each carry six small guns, besides two tubes from which to discharge 18-inch torpedoes containing nearly 200 pounds of gun-cotton and costing £500. All these torpedo craft of various type have cost over eight million sterling.

Such is the strength of the British Navy, and its cost to the nation in the first instance. Millions of pounds have since been spent in maintaining all these ships in efficiency. From the great battleships of the *Formidable* type to the smallest torpedo-boat, they are experiments. All we know is that the best inventive genius has produced these ships on definite scientific principles, and that they represent £108,000,000, made up as follows:—

64	battleships	52,000,000
15	coast defence vessels	3,100,000
22	cruisers, armoured	11,327,000
119	" protected	29,037,000
16	" unprotected	2,236,000
35	torpedo vessels	2,300,000
120	torpedo boat destroyers	6,000,000
98	torpedo boats	2,000,000
489		£108,000,000

In this statement no account has been taken of many important ships now building or projected. These include the four new battleships of the *Duncan* class, of 14,000 tons displacement each, and the two battleships of the 1899-1900 programme, the designs of which have not been settled. A feature of recent programmes has been the attention devoted to armoured cruisers. There are fourteen of these ships building or projected. At a rough estimate these twenty armoured ships represent about sixteen million pounds sterling, and there are seven third-class cruisers, not included in the above estimate, which will have cost over one million pounds by the time they are ready for sea. If the cost of these twenty-seven ships be added to the aggregate cost of the navy, the total would be increased to just under £125,000,000.

These are the iron walls that, in time of need, will stand between us and an enemy, which safeguard commerce, protect the colonies, and are continually patrolling the ocean highways. Our commerce is greater and our colonies are larger and more prosperous than the dependencies of any other country; and who, therefore, can doubt that this colossal sum,—£108,000,000,—has been well laid out? It is a part of the funded capital of Great Britain's formidable system of insurance against a foreign foe.

SOME CONDITIONS OF THE AMERICAN IRON AND STEEL INDUSTRIES

AS SEEN THROUGH BRITISH EYES

By Walter Dixon, M. Inst. M. E.

IT has been said that, while speaking our own language, the manners, customs, and practices of the Americans resemble our own less than do those of the foreign-speaking countries of Europe, and there is no doubt that in many ways this is so. One is being constantly astonished at their different ways of working and different methods of dealing with things, and a constantly recurring surprise to the writer during a recent visit to the United States was why anybody should ever have gone to the trouble to devise other methods than those which had been used in Great Britain so long.

There are a thousand and one differences which strike one more or less forcibly,—some good, some bad, and some doubtful,—and a few of these the writer discussed recently before the West of Scotland Iron and Steel Institute, confining himself principally to three points, — management, labour, and resources.

MANAGEMENT

Under the head of management, the writer took under consideration the practice which has numerous and very wide-reaching issues, viz., the almost supreme control exercised by young men over the largest and most important industries. One of the first things to impress a stranger is that the most enormous concerns are very largely managed and controlled by young men. The writer was not surprised that, so far as the electrical business was concerned, this should be so, seeing that is a more or less new development; but the same practice seems to prevail throughout.

There is a tendency in Great Britain, when this fact is stated, to ask:—Where are the old men? and to conclude very generally that the pressure of work in America may cause an early mortality. This may or may not be true, but that the young men control very largely the business concerns of America cannot be denied. The writer took occasion to talk over the matter with many friends whom he met, and perhaps the best generalisation of the American's sentiment might be defined by the saying of the principal of a large concern, with representatives in all the large cities of the States, and whose managers are all under 35 years of age, when he stated that "he and his countrymen had come to the conclusion that a young man's intuitions were as much to be depended upon as an old man's deliberations," and that "you got there much quicker."

This, of course, is largely antagonistic to British practice, which may arise from habits and methods formulated when the world went very much slower than now, and when we regulated the pace. There are yet many businesses and professions in which experience, extending over a wide area and over a long space of time, is of first importance, but the rapid progress which is being made in almost every art and every in-

dustry is such as to render obsolete methods which a few years before represented the highest and best practice. So much is this the case that adaptability to change and the absence of that conservatism which comes of long practice in one particular groove is often the one and only road to success, and in many of our industries it is necessary to be constantly unlearning or revising what one knows.

The Americans appear to recognise that there comes an age when this may be both physically and mentally beyond possibility, and they have fixed that age much lower than ourselves.

The writer does not wish to imply that there are no elderly men at the head of American business concerns. He met several, but the most noticeable feature about them was the apparent reliance which they placed upon the army of younger men under their direction in quite a startling contradistinction to the prevalent system here. It was more than once represented to the writer that, while they were delighted to see and receive visits from the fathers of the British iron and steel industries, they felt that we should stand a much better chance of profiting by any advances and improvements which they made from time to time if our younger men, who are more sensitive to new impressions, would go.

It was said by an old French savant, in one of his most satirical moods, that "if you wish truth and certainty, go to the young, they know everything." There is no doubt that if one wanted to be satirical about our American friends we might say, "If you wish truth and certainty, go to America, they know everything." But, after all, and after the satire had had its legitimate effect and weight, where else should we look for the best and most up-to-date knowledge and practice than to America? As a nation, they have a full measure of energy, will, and ability, and have taken and are taking every available means to know the results of the best practice, and with their new country, with its unlimited resources and unlimited capital ready to hand, they are indeed the heirs of all the ages.

We are at all times ready to acknowledge the inventiveness of our American cousins. They are always trying, experimenting and inventing, and this is largely and mainly due to their young men leaders. Men with ideas receive encouragement and ample opportunities of proving their worth. One of the most important American firms so far encourage their employees to improve their plant that they will pay all the cost of trials and all patent fees which are vested solely in the employee, the company reserving only the right to the free use of the invention in their own works. Thus it is, that while we are making a hundred experiments, 80 per cent. of which may be failures, the Americans are carrying out a thousand, 90 per cent. of which may be failures; but their gain is a hundred good things, while we have gained twenty! They lose far more in their trials; they gain far more in their successes.

So far as the writer could judge, the American appears perfectly fearless of foreign competition, and is a staunch believer in the survival of the fittest; and, what is more, that the weak will go to the wall. He knows that if he is weak, he will go to the wall, and is hence always on the move to do something clever. You can see it in the iron and steel business and everywhere. It is this which makes them what we should call "foolhardy" with one another, and, if one may so put it, with ourselves; they do not care who sees what they are doing. Their works are equally open to the stranger and to the competitor. It seems an inbred idea with them that if they cannot themselves keep up to date, and be at least as good as, if not better than, their neighbours, they are bound not to succeed. This at once accounts for their many successes and their many failures.

LABOUR

In visiting and comparing the industrial centres of the world, we find three sets of conditions prevailing, depending on the cost and supply of labour. On

the Continent, where labour is cheap, we find that the system adopted is a maximum of labour and a minimum of mechanical appliances; here, in Great Britain, where labour is not so cheap, we have a more equalised division of mechanical appliances and labour; while in America, where labour is expensive and relatively scarce, there is a maximum of appliances and a minimum of labour. In going over the iron and steel works, in fact, any of the American works, we cannot fail to be struck with the scarcity of operatives, and the writer on many occasions refrained from using his camera on account of the absence or fewness of any men in the field, giving a " closed down " appearance to works which were, however, in full swing.

The fact that America has suffered from expensive labour, and, what is more, an absolute scarcity of skilled labour, has led up to their having become specialised for, and in, their labour-saving machinery, and as such, they are the best exponents of an art which, for more than one reason, has not flourished here. They have far greater faith in machinery than we have, and the writer was told by the director of one company that they were always prepared to spend from six to ten thousand dollars on a machine which will replace one skilled man, and their works certainly appear to verify the statement. The fewness of workmen is not, however, more strange than the activity of those who are employed.

The writer has been intimately connected with large numbers of our workmen for the past twenty years or more, and has talked labour questions over with many classes in America, with the conclusion that, just as our own men, generally speaking, are bent on doing as little as possible in a given time, the American workman is bent on doing as much as possible. While individually, outside his work and often at his work, the British working man is all that we could wish, and such as was bound to place Great Britain in the forefront of the industrial countries of the world, he has, from many causes (which we know of and which he knows of) for many years past come to consider that the main question in his life is, how much he is going to get for the time he spends at his work or at the workshop, with little regard as to what he is going to give in return.

There is one point in which all employers of labour are unanimous and that is, that one of the most serious problems to be faced is the want of conscientiousness and integrity in British labour. There is no need to go into detail, for the fact that our workmen systematically do not,—not to say are not allowed to,—put forth their full and reasonable energies is notorious, and we may be spared the necessity of demonstrating outside that which is so amply demonstrated every hour of the day inside almost every workshop which comes under the control of our trades unions.

British labour, both skilled and unskilled, appears, either by design or accident, to have worked itself into the condition that each trade individually vies with the other, and the whole combined trades vie together in discovering the greatest amount that can be extracted in wages out of each and every piece of work. In their individual interests they will quarrel about demarcation lines, and collectively they are, in the execution of their own work, careless of the work of those who preceded or are to follow them. If our workmen were now, as in the past, the sole masters of the manufacturing world, such a state might exist an indefinite period. Such, however, is not the case. They are not the sole masters, and the days of such labour conditions are numbered.

Americans seem to have grasped this very forcibly, and while they have had, and probably will have, their labour troubles, they are not on identical lines with our own. They have their piecework, and bonus systems, and a man gets paid for work honestly done,—not for time spent. I believe the American workman generally is industrious, sober, is to be depended on, and has an interest in his work, and when paid by the

hour, realises that if he receives wages for time which he has deliberately loafed and wasted, he is dishonest. Do our men know it, and if they do, what do they care?

The American artisan earns more wages than our own, but he does more work and thus often produces at a cheaper cost, and it must be obvious that if we are to maintain our position one of the greatest needs of the country is, that it shall be able to get an honest day's labour for an honest day's pay. If our labour leaders would put their energies in this direction they would find ample scope, and if they could induce their well-drilled battalions to fall into line they would not find the wages question such a serious one as it is now, and they might secure a spell of prosperity to the country which cannot possibly be maintained indefinitely under the present artificial, iniquitous, demoralised, and demoralising system.

RESOURCES

The writer had a letter recently from a friend, now in America, in which he says:—"I am located here, almost in the backwoods, nothing to see but the works, mountains, and forests. I have been down in the Great Southern iron-making district where they make pigs and put them into cars for 26s. This is, without doubt, a gigantic country, with millions of acres that have not yet seen the foot of man. I try to imagine this State being as large as England, for such it is, our nearest town with 40,000 inhabitants being 40 miles away, and our nearest big town being 300 miles away."

The writer has, from time to time, travelled over a good part of Europe, and thought, in going to America, he should, in the way of distances and size of country, have no new experiences, but it was quite otherwise. Unless one has been in America, one can have no adequate idea of its size and of its enormous resources.

For the first time in the history of the world and of a highly civilised nation, we who, mainly through our large iron and coal deposits, have risen to be the foremost nation in the world, have now to face the fact that these resources which have made us what we are, and which are irreplaceable, are fast becoming exhausted. We had iron ore in England and Scotland once,—there is a good deal in England yet,—which, in the light of recent events, may or may not be all that is hoped for it; but in order to maintain our Scotch blast furnaces we go to Spain, we are talking of going to Sweden, and we are prospecting everywhere to find future supplies, and it has recently been reported that some of our blast furnaces have been seriously hampered for the want of ore. We have for so long held and maintained an impregnable position that we are naturally of a buoyant and sanguine temperament, so much so that it is difficult to comprehend the exact position in which we now stand, and that we hold anything but the supreme and topmost place in any industrial pursuit is such a new idea that, as a nation, we may be forgiven our slowness to realise it.

The progress of the American iron and steel industry has advanced by leaps and bounds, and at a rate which is almost incomprehensible. Nobody would have ventured to predict twenty years ago that before the end of this century the Americans, instead of importing from, would be exporting iron into Great Britain and be serious rivals in all British foreign markets, and we have not yet, as a nation, accustomed ourselves to the idea that our neighbours across the water, who are brethren with us in civilisation, energy, and ability, have at their very doors, in inexhaustible quantities, all the resources which were instrumental in putting Great Britain into her prominent position. That the Americans will continue to harass British foreign trade, nobody doubts. Whether they will continue to compete with our own manufacturers here in good and bad times remains to be seen, though in the minds of the Americans themselves, and those of our nation who best know America, there is little doubt.

The fact that all our works are now taxed to their full powers, and that we

have more trade than we can get through, should not blind us to the fact that our hitherto supreme position is seriously menaced, and that while a few years ago we stood independent and alone and able to dictate our own terms, we now have to reckon with other and seriously formidable rivals. That we cannot now supply the world with its requirements shows that the world is bigger than it used to be; and that so many orders have to go abroad may mean that, instead of getting the lion's share or more, as has been our habit, we may now be getting only a fair share, and that when harder times come, we may get less than our share.

With all this, one thing at least must be clear, *viz.*, that any position we may maintain will be only due to the fact that we can produce and carry as cheaply as our competitors. Our ore supply, as we have said, is, or may soon be, a problem, and as to the other main factor, coal, the future is not so clear as it might be. The government enquiry into the coal resources of Britain held about thirty years ago showed that we need have no fear for our coal supplies for some hundreds of years at least, but this is not much to the point. The question is,—how long will our cheap coal last,—coal which shall not only be as cheap as that of our competitors, but relatively cheaper, in order to help us through with our other more expensive items,—our ore, freight, carriage, labour, and in many cases an absence of the most economical working plant? It is very difficult to get any exact data as to our readily available and cheap coal supplies, but I believe that twenty-five years hence the main and cheaply wrought coal seams in Scotland will assume an aspect which will require to be seriously recognised and faced. In the meantime, we use and export our fuel as though our supplies were inexhaustible.

ELECTRICITY

The difficulties which have been experienced in getting suitable labour has led the Americans to have a supreme faith in machinery as against hand labour, and perhaps the writer could not better convey the idea of the part played by electricity than by stating that it is now a recognised branch of engineering and plays a prominent part in conjunction with steam, compressed air, and hydraulics. The universal experience in America has been that the electric motor has proved quite as dependable as the plant which it replaced. Two companies had each on order generators of 1000 H. P., which size they regard in the same light as we regard machines of 100 H. P. We are beginning to recognise more and more the necessity of knowing American practice, and with no branch is it more necessary to be conversant than with electricity, if one would wish to be "up-to-date."

Owing to more than one cause, we are perhaps as much behind Continental practice as Continental practice is behind American. In one particular class of machinery with which we in this country are practically non-conversant, the writer found that one of the leading firms in America had already manufactured and set to work over a quarter of a million H. P.

One of the most striking features in which they have developed labour-saving is in the use of cranes and innumerable carrying and lifting appliances, and in this direction electricity has proved one of their most valuable servants. In the stock-yard of one works a man in an elevated cabin controlled about eight sets of live rollers. It was a pleasure to see many of the machines at work, and driven electrically, about which papers are read in this country, and on which discussions, often unfavourable, are not wanting. Amongst these were the Uehling casting machine, Wellman steel furnace charger, blast furnace chargers, cranes, and travellers, in various forms, and a very general use of motors where we employ small engines.

In conclusion, the writer would wish to emphasise the few following points:—We have made and hitherto held our national supremacy through three amongst other causes:—1st, Our coal

and iron supplies; 2nd, Our superior workmen and work; 3rd, Our capital.

Even assuming for the moment that we have these still, the fact remains that we have not as we once had, the monopoly, but we have now serious competitors with whom we have to measure our strength. As to how serious this competition is, let us look for a moment specially at our American competitors. They are of the same blood as ourselves and that means a good deal; we are not measuring our strength against unworthy foemen. Again, their young men make the pace, probably the men who spend the money are not those who make it. They build works, pull them down, and rebuild them on improved plans, with a rapidity that is truly astounding and incomprehensible either physically or financially, so much so that some of our attempted partial copies of American practice were regarded as obsolete there before we had got them erected.

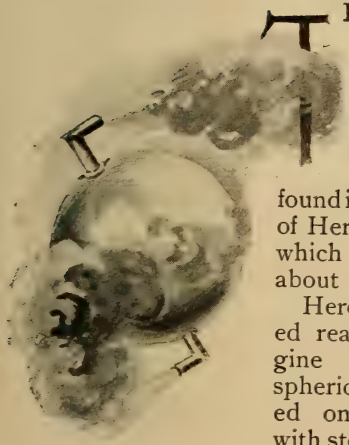
They institute gigantic trade combinations which we may imagine they will cease to do when they have more experience. This may be where the money is really made or it may not, but meanwhile, and for years to come, such combinations and business tactics may seriously harass legitimate trade and legitimate prices. Further, their country is new, and their trade is not embarrassed by all the ties and restrictions which come of such an old civilisation as our own. Their industries are new, and their works are all on the most modern principles, and they have an inborn idea that they must be kept so. The question which so often troubles us, "Will it pay to break up and replace?" is not serious with them.

One of the great effects of American competition may be, that our works will have to be remodelled so as to obtain all the advantages of later practice. If we can hold our own with our present plant, then we have a good margin yet on which to work, for there is a vast scope for modernising and improving. As to the labour question, it will no doubt find its level, though what injury may be caused individually and nationally in the process one can only surmise. One thing is clear, that no amount of restrictions which may be made as to hours, output, wages, etc., will alter "the impossible," and we are getting more and more able to define every day more clearly what is "the impossible." The increasing number of orders going to our competitors is a constant lesson in possibilities and of the effect and futility of artificial restrictions on labour. These lessons used to come slowly; they come now with an accelerated and ever-quickening pace. There is an old adage about "locking the stable door after the horse has gone!" To maintain our position, our workmen must be sober and industrious, and prepared to give an honest day's labour for an honest day's pay.

Conditions obtain in America which must of necessity evolve methods of manufacture of paramount importance to us; and just as the Americans are not slow to visit us for information, so it is equally important, if not imperative, that those who now play or are to play, in the immediate future, an important part in the iron and steel industries in the United Kingdom, should not be content with reading of, but should know and see for themselves, what is being done in the works of America.

DEVELOPMENT OF THE STEAM TURBINE

By Hon. C. A. Parsons



THE earliest records of attempts to obtain motive power from the combustion of fuel are found in the Pneumatics of Hero of Alexandria, which dates back to about 200 B. C.

Hero's often described reaction steam engine consisted of a spherical vessel, mounted on axes, supplied with steam through one of the trunnions from a boiler beneath. The steam escaping through two nozzles diametrically opposite to each other and tangential to the sphere, caused the sphere to rotate from the reaction or momentum of the steam discharged in the opposite directions. Hero also describes what is virtually a hot air engine of the most primitive form.

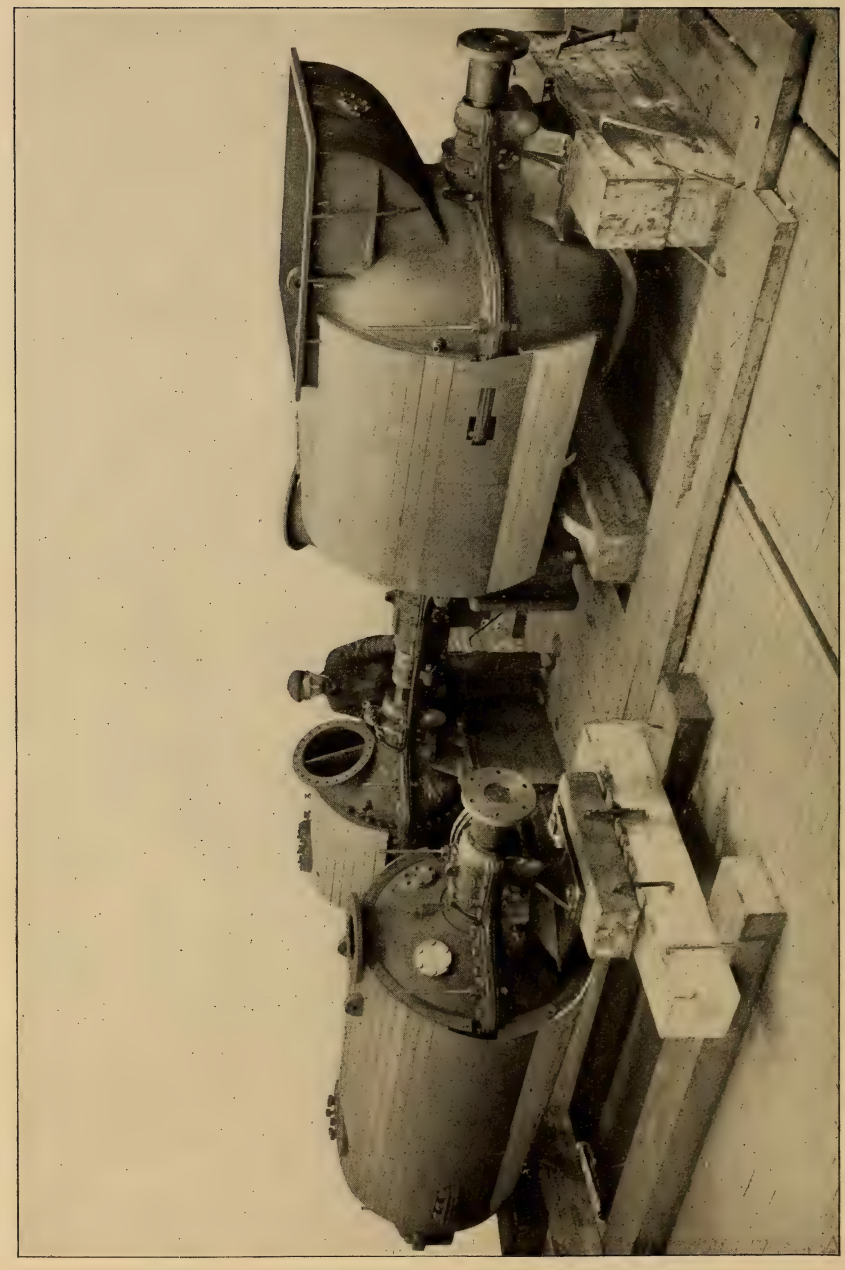
Hero's engine, though extremely crude and wasteful in fuel, was capable of doing useful work, and was a veritable steam engine and the first of a genus, the "turbine engine," of which there are, at the present day, thousands of horse-power at work, and which in its more perfected form, may supersede the piston engine in many of the most important fields of motive power in which, until recently, it has enjoyed a monopoly.

Steam engines, in general, may be divided into two classes,—the "turbine engine," more correctly described as a "dynamical" or "momentum" engine, driven by the momentum of the steam issuing at high velocity; and the "piston" engine, driven by the statical pressure of the steam against a piston. These two types appear, at the present time, to afford the only practicable methods of utilising the energy of steam from a steam boiler for useful mechanical work.

The writer has tested a well-made reaction engine, identical in principle with Hero's, and found a steam consumption per horse-power lower than in many engines in commercial use in the present century and even at the present day. While, thus, it is a curious fact that the engine of Hero had all the elements of success, it obtained no commercial application, and no kind of steam engine was put into practical use till the seventeenth century. The Marquis of Worcester revived the subject in 1663, followed closely by Savery with his pumping engine.

Newcomen's piston pumping engine in 1705 was undoubtedly the first member of the piston engine genus, but towards the end of the century James Watt developed the double-acting steam engine with connecting rod and crank, the veritable and immediate forerunner of the locomotive and marine engine of the present day, and he also added the great invention of the separate condenser, applicable alike to all classes of steam engine.

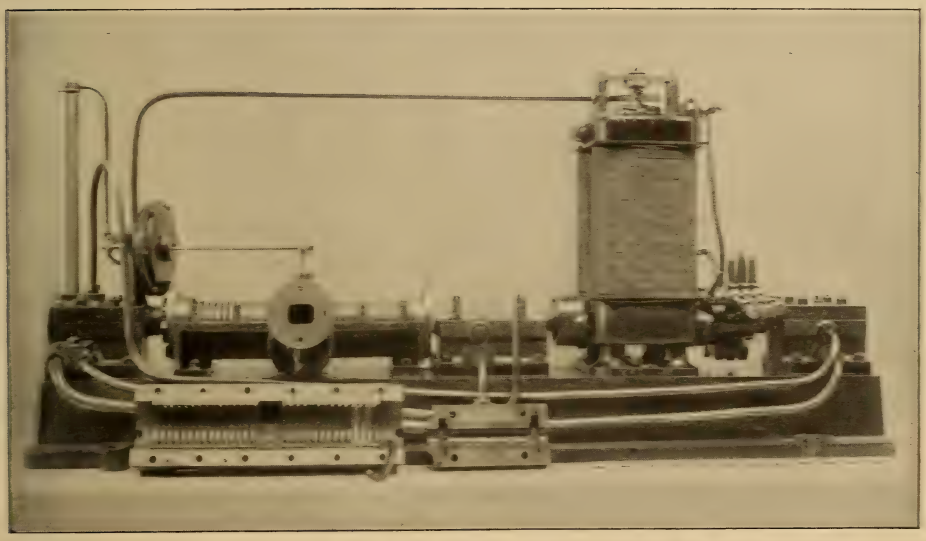
Improvements in piston engines then followed in rapid succession, but the poor steam turbine engine appears to have been almost completely neglected. It ran too fast for practical men; as then made, it took too much steam; and since its inherent power and merits were not appreciated, it was completely overshadowed by its more robust rival, the piston engine. The pressure of steam on a piston could be felt to be almost irresistible, but the little steam jet, issuing at immense velocity, seemed feeble and



A SET OF PARSONS STEAM TURBINES, PORT SIDE, FOR A 35-KNOT TORPEDO BOAT DESTROYER NOW BEING BUILT FOR THE BRITISH GOVERNMENT

wasteful in steam and of no practical use. Giovanni Bianca attempted to introduce Hero's principle in 1629 in another form, by causing the steam jet to play against vanes attached to the rim of a wheel, but with no practical success.

The coming of the dynamo-electric machine, however, about fifteen years ago, and the development of electrical and mechanical engineering, created a demand for a good engine suitable for the direct working of dynamos and fast-



A 10 H. P. TURBINE, BUILT IN 1884, NOW AT THE SOUTH KENSINGTON MUSEUM, LONDON

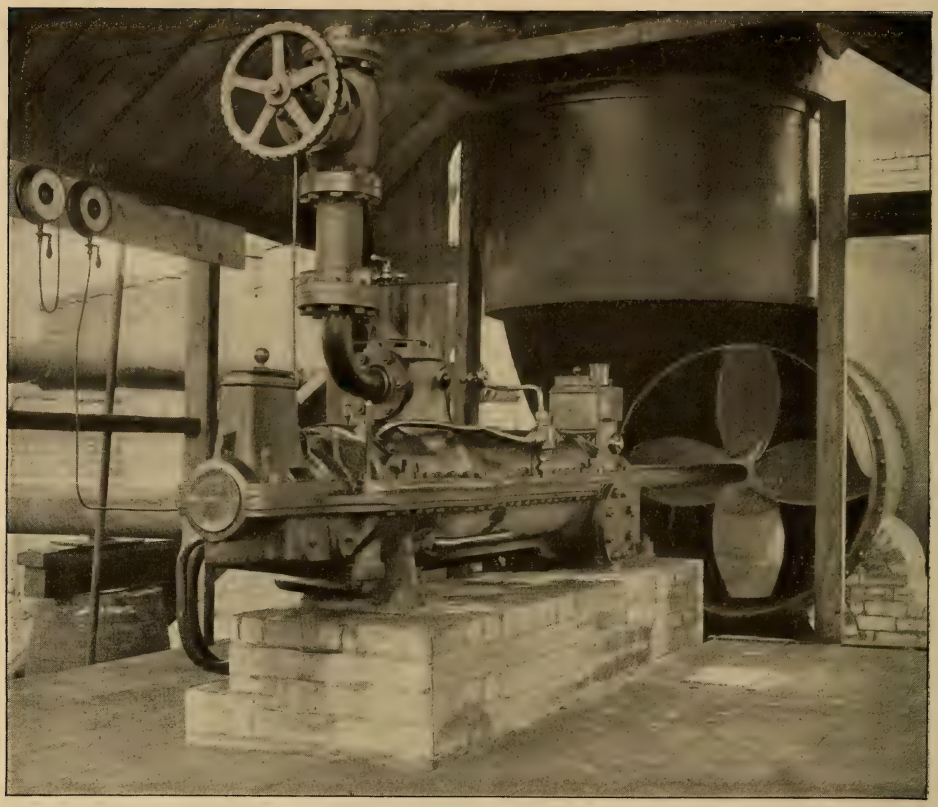
running machinery. Engineers were becoming more accustomed to high speeds of revolution, for the speed of dynamos was then from 1000 to 2000 revolutions per minute, of centrifugal pumps from 300 to 1500, woodworking machinery from 3000 to 5000, and Sir Charles Wheatstone had made a tiny mirror revolve at a speed of 50,000 revolutions per minute.

The problem presented itself to the writer of constructing a steam turbine, or ideal rotary engine, of good steam economy, and with a comparatively moderate speed of revolution, so as to permit of its being coupled directly to a dynamo. At the same time the ordinary dynamo required modification to raise its working speed to the level of the slowest permissible speed of the turbine engine.

In 1884 preliminary experiments were commenced by the writer at Gateshead-on-Tyne, England, with the view of dealing practically with the question, and ascertaining by actual trial the conditions of working and equilibrium of shafts and bearings run at such high speeds as are essential in steam-turbine engines. Trial shafts and bearings were made and run by belts to the excep-tionally high speed of 40,000 revolutions per minute, at which speed no difficulty was experienced, providing that a certain amount of elasticity was provided for in the bearings and also an ample supply of lubricant.

In the same year a 10 horse-power turbine engine and a modified dynamo were designed and constructed for a working speed of 18,000 revolutions per minute. This machine proved to be practically successful, and subsequently ran for some years, doing useful work. It is now in the South Kensington Museum.

Calculations as to the velocity of issuing steam led to the design of the turbine engine on the compound prin-



A 100 H. P. TURBO-FAN AT CLARA VALE COLLIERY NEWCASTLE-ON-TYNE, ENGLAND

ciple, consisting of a number of successive turbine wheels, or rows of blades, on one drum or shaft, within a concentric case, the moving blades or vanes being in circumferential rows projecting outwardly from the shaft and nearly touching the case, and the rows of fixed or guide blades projecting inwardly from the case and nearly touching the spindle. A series of turbine wheels on one shaft were thus constituted, each one complete in itself, like a parallel flow or Jonval water turbine, through which the steam was forced to pass. Each successive turbine was also slightly larger in passage way than its predecessor, to allow for the increasing bulk of the elastic steam, as it exerted its force on each turbine successively and expanded with the consequent reduction of pressure.

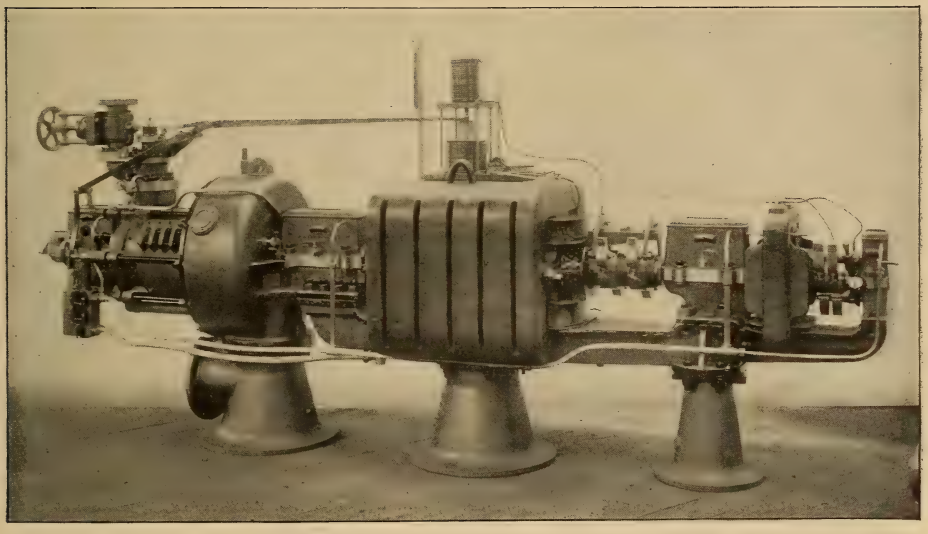
Many questions had to be considered, such as the end balancing from steam pressure by a double set of turbines on each side of the steam inlet, continuous lubrication of the bearings, and the providing therein of a small amount of elasticity; but the main question was the reduction of speed of the engine without loss of steam efficiency, and this was met by the compound principle which reduced the speed of the steam passing through the turbines by dividing up the fall in pressure, and so permitted of the necessary peripheral velocity of blades for economical working without an excessive or dangerous speed of revolution.

Improved and larger turbines were rapidly made and placed on the market. In 1889 turbine alternators of 100 horsepower were placed in the Newcastle & District Electric Lighting Company's station. In 1891, when some thou-

sands of horse-power were at work, the first steam turbine alternator of 200 horse-power, at 4500 revolutions per minute, adapted for condensing, was constructed, and gave a remarkably high steam efficiency.

As described by Professor Ewing, F. R. S., the general result of the trials is to demonstrate that the condensing steam turbine is an exceptionally economical heat engine. The application to it of moderately superheated steam has put the performance of the turbine on the level with that of the best steam engines of the ordinary type. A consumption of 27 or 28 pounds of steam per electrical unit, at full load, and 30 or 32 pounds at half load, is a result that does not need to have its significance emphasised. The efficiency under comparatively small fractions of the full load is probably greater than in any steam engine, and is a feature of special interest in relation to the use of the turbine alternators of the condensing type were placed in the Newcastle and District, and Cambridge and Scarboro electric supply stations, and soon after a large number of 600 and 800 horse-power, of the non-condensing type, driving alternators, were placed in several of the Metropolitan Electric Supply Company's stations in London, the complete absence of vibration being of the utmost importance in this instance, and the turbine plants fulfilling this condition to perfection. Turbine alternators are now being made of 2000 horse-power and upwards in Great Britain and in the United States, and larger sizes are being designed. It may be said that the larger the size the more conspicuous become the relative advantages over piston engines.

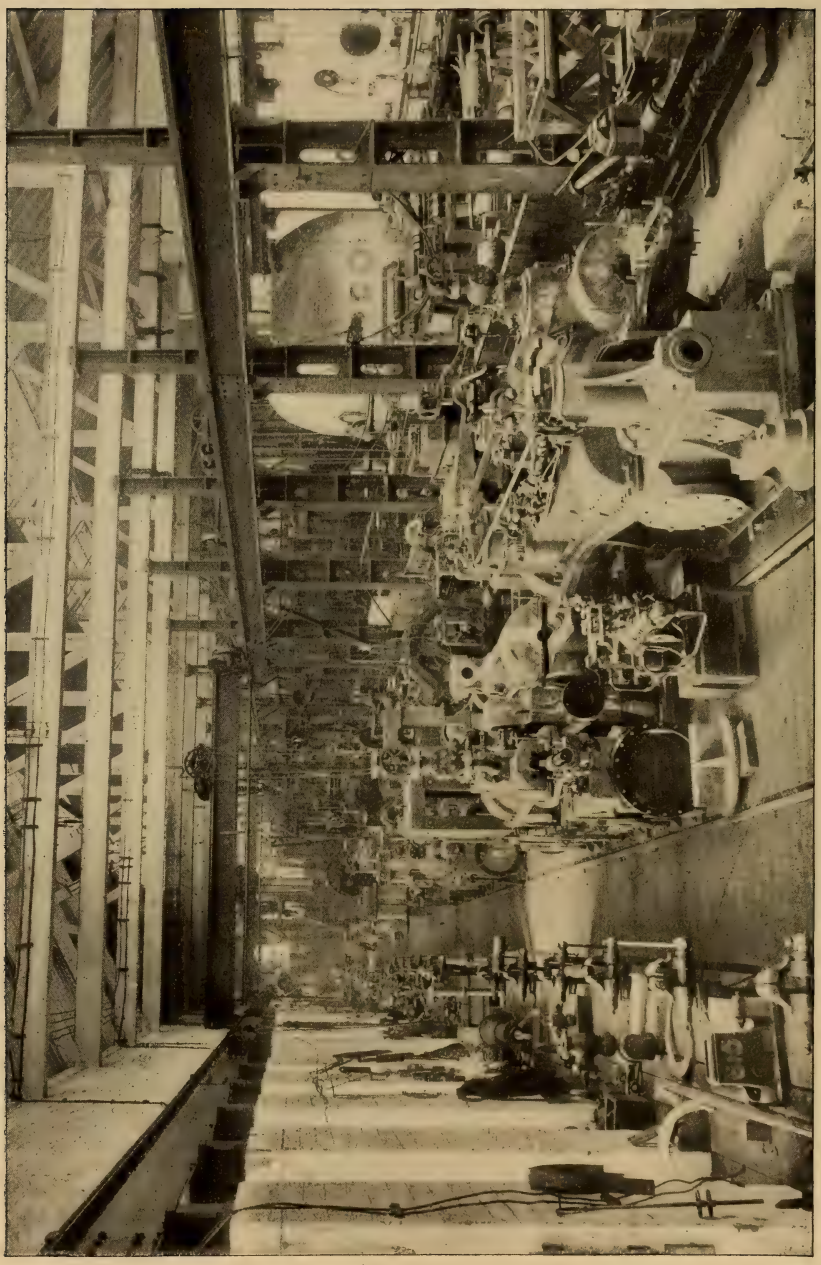
Turbine engines are used in many places for generating electrical current for motive power purposes. At Black-



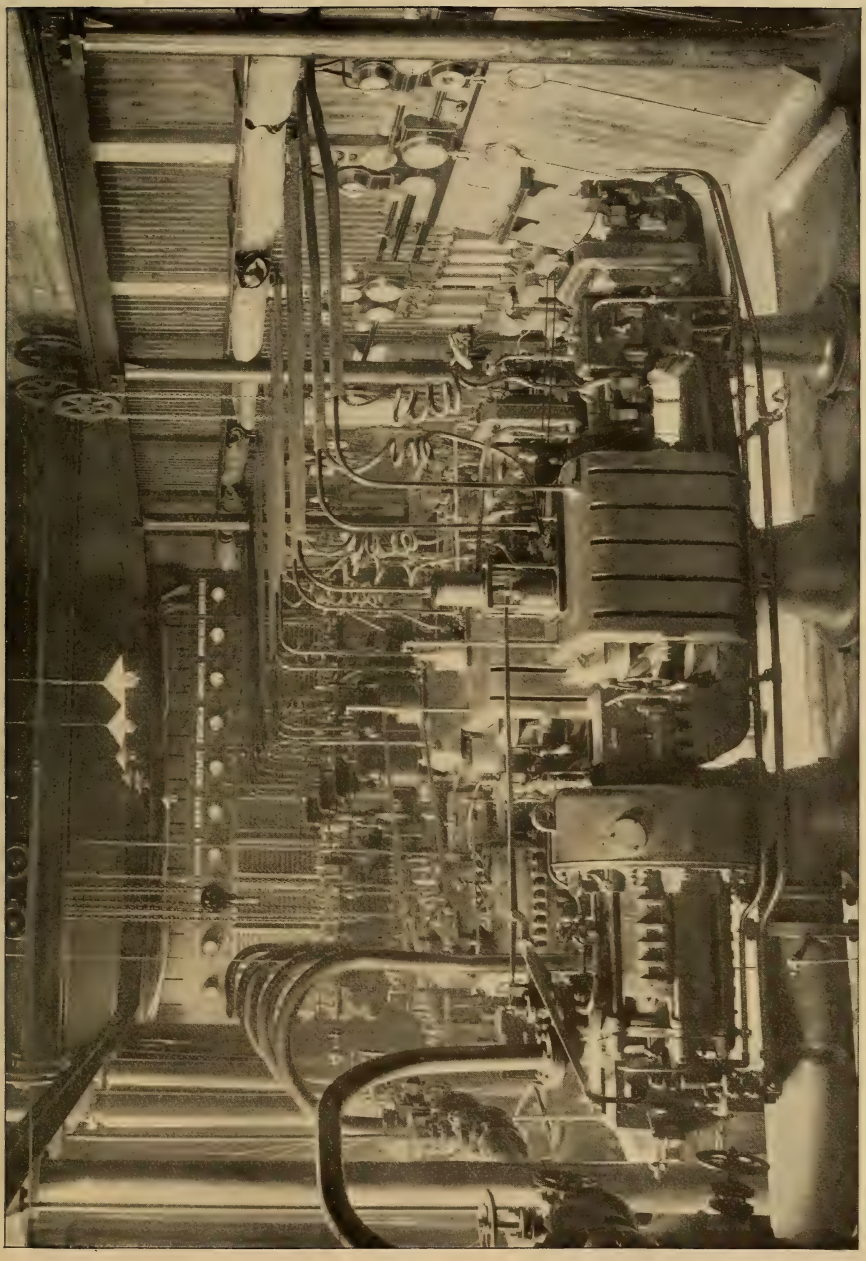
A 200 H. P. TURBO-ALTERNATOR

turbine in electric lighting from central stations.

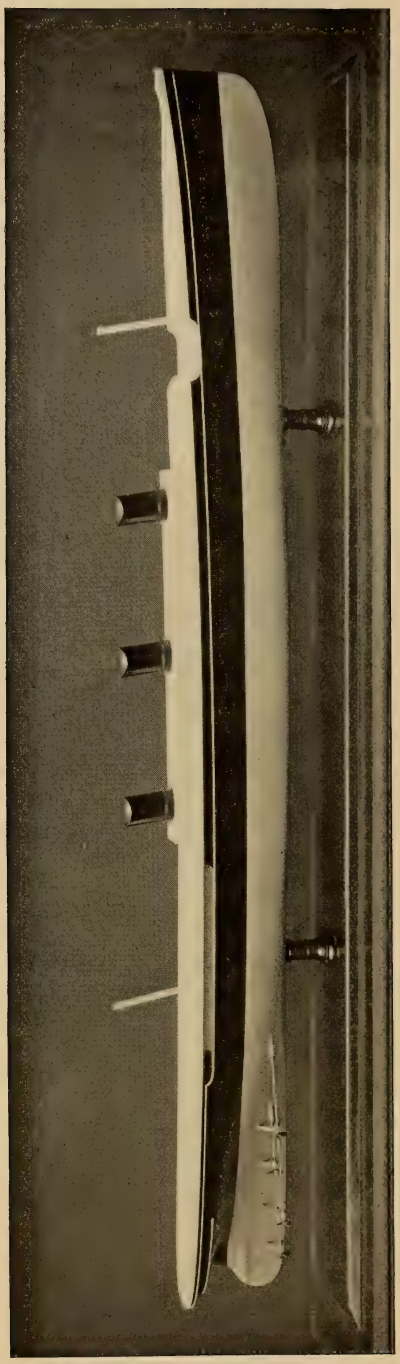
This result marked an era in the development of the steam turbine and opened for it a wide field, including some of the chief applications of motive power from steam. At this period pool, England, and other towns they work the electrical trams; at collieries they generate power for electrical coal cutters and other purposes, and are coupled directly to, and drive, screw fans for colliery ventilation and forcing the draught of boilers, and drive also



THE ERECTING SHOP OF THE HEATON WORKS AT NEWCASTLE-ON-TYNE, WHERE THE PARSONS STEAM TURBINES ARE BUILT



THE NEWCASTLE AND DISTRICT ELECTRIC LIGHTING COMPANY'S STATION AT NEWCASTLE-ON-TYNE, ENGLAND, EQUIPPED WITH PARSONS TURBINES



MODEL OF A PROPOSED ATLANTIC LINER TO BE PROPELLED BY PARSONS TURBINES.—LENGTH, 600 FEET. BEAM, 63 FEET. DEPTH, 42 FEET. DISPLACEMENT, 1800 TONS. SPEED, 27 KNOTS. I. H. P., 38,000

centrifugal pumps for raising water. The result of continual experiment and improvements have further led to a considerable reduction of steam consumption since 1891, and a 900 horsepower condensing type alternator, recently made, converted 61 per cent. of the energy of the steam into electrical output, —a result unparalleled with the piston engine. To give some idea of the extent to which turbines have been applied to the generation of electricity, it may be mentioned that the aggregate horse power supplied for all purposes at the present time exceeds 60,000.

Some of the advantages claimed for steam turbines over ordinary engines are:—Small space occupied, and small weight; less first cost; reduced upkeep and attendance; better governing on account of the immense momentum and even turning effort of the engine; a disregard of costly foundations, as the engine requires no bolting down; no lubricant enters the steam space, and the exhaust is, therefore, absolutely free from oil, greatly to the benefit of the condenser and boiler.

In the year 1889 Dr. de Laval, of Sweden, patented an improved form of Bianca's steam turbine wheel, and with considerable ingenuity and practical grasp of the subject has attained satisfactory results and considerable commercial application on the Continent. In this turbine, as in Bianca's, the steam expands in one operation in its exit from a divergent conical jet, and to obtain economical results it is necessary that the peripheral velocity of the pallets and wheel must be very great; thus, for most purposes some form of gearing is essential, and a form of double helical gear with fine teeth has generally been used with this turbine.

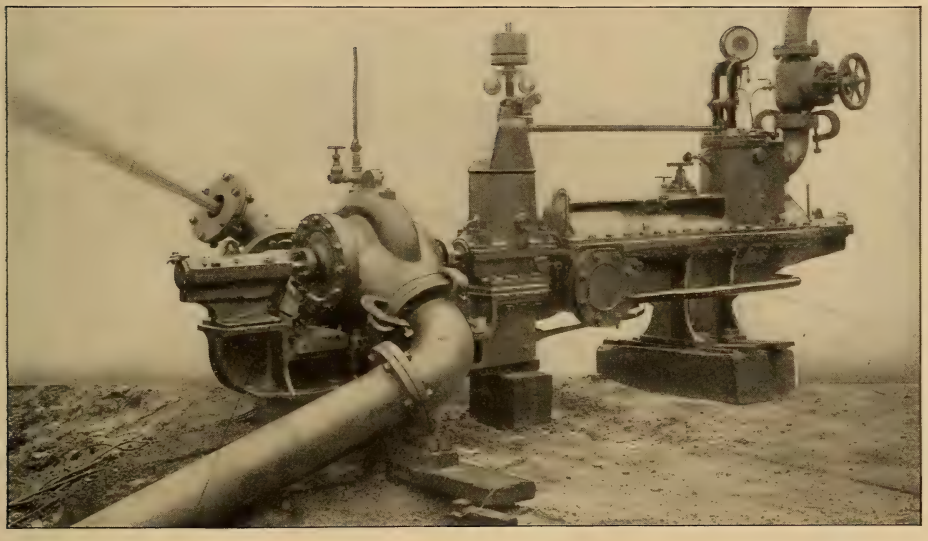
The most important field for the steam turbine is in the propulsion of ships. The large and increasing amount of horse power and the greater size and speed of the engines tend towards some form of engine which shall be light, capable of perfect balancing, and economical in steam. The present-day marine engine does not entirely fulfill all these requirements, nor indeed can

it be reasonably expected to do so; but the compound turbine engine, as made in 1892, appeared to be capable of adaptation to marine purposes and of fulfilling the necessary requirements of an ideal marine engine. One important element of uncertainty lay in the high speed of the turbine engine, and to couple it directly to a propeller of ordinary proportions would certainly have led to failure.

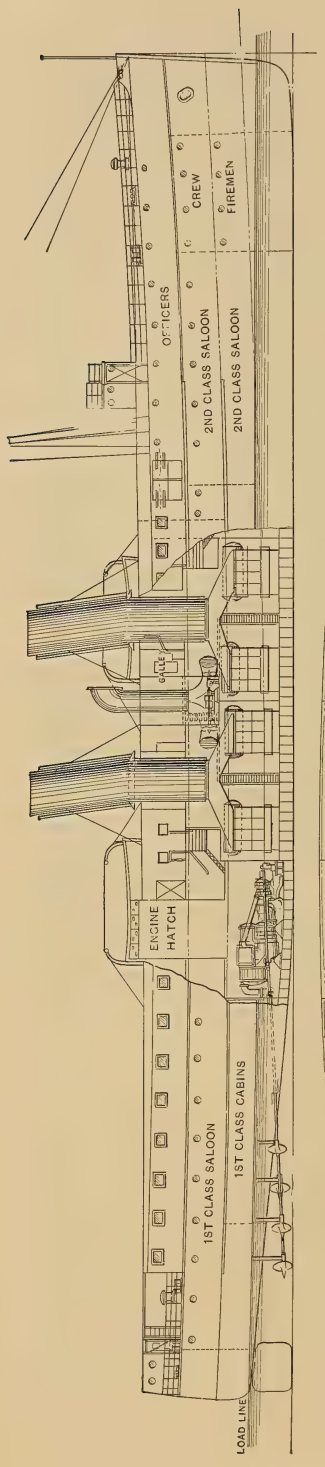
In January, 1894, a Pioneer Syndicate was formed in England to explore the problem, those chiefly associated in the undertaking being the Earl of Rosse, Christopher Leyland, John B. Simpson, A. A. Campbell Swinton, Norman Cookson, the late George Clayton, H. C. Harvey and the writer. It was deemed expedient for reasons of economy and also of time (as many alterations were anticipated) to build as small a vessel as possible, but not so small as to prevent her from attaining an unprecedentedly high speed should she be successful.

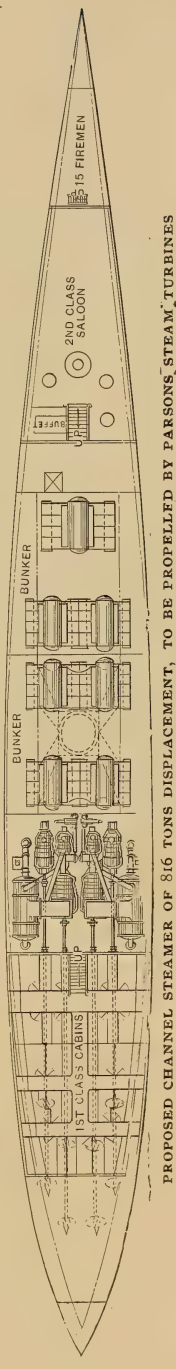
Ample funds were available and the *Turbinia* was constructed. Her dimensions are:—100 feet in length, 9 feet beam, 3 feet draught of hull, and 44 tons displacement. She was fitted with a turbine engine of 2000 actual horse-power, and an expansive ratio of 150 to 1, and also with a water-tube boiler of great power, of the express type with small tubes. The turbine engine was designed to drive one screw shaft, at a speed of from 2000 to 3000 revolutions per minute.

Many trials were made with screw propellers of various sizes and proportions, and the best results were obtained with propellers placed some distance apart from each other on the shaft; but the best speeds were quite disappointing, and it was clear that some radical defect lay in the propellers. This was corroborated by dynamometric measurements. The excessive slip beyond the calculated amount and the inefficiency of the propellers all pointed towards insufficiency of blade area upon which the thrust necessary to drive the ship was distributed; in other words, the water was torn into cavities behind the blades. These cavities contained no air, but only vapour of water, and the greater portion of the power of the engine was consumed in the formation and maintenance of these cavities instead of in the propulsion of the vessel. This phenomenon was first noticed a

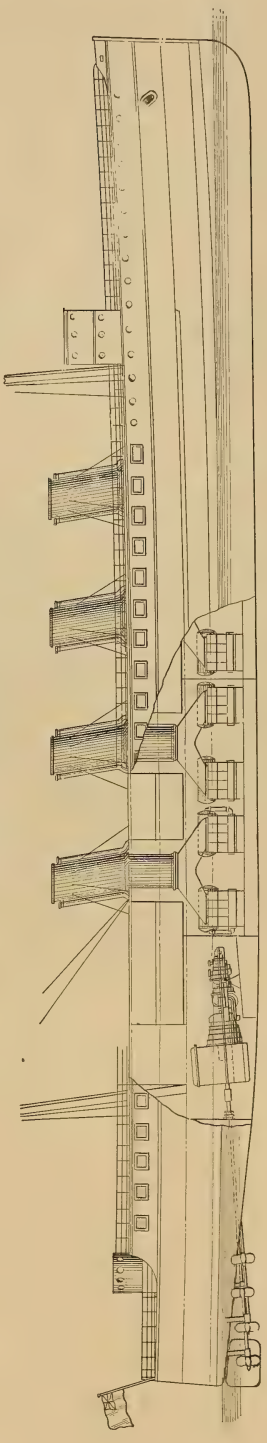


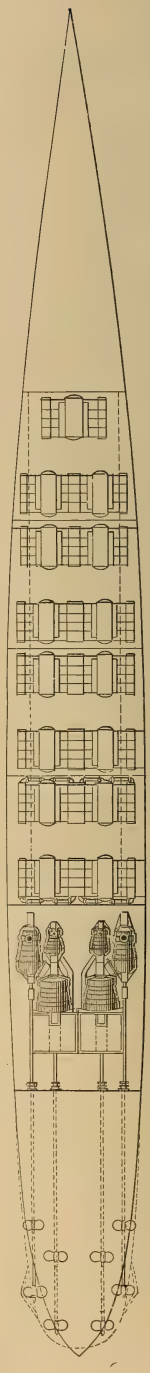
A CENTRIFUGAL PUMP AND STEAM TURBINE COMBINATION





PROPOSED CHANNEL STEAMER OF 816 TONS DISPLACEMENT, TO BE PROPELLED BY PARSONS STEAM TURBINES





AN EXPRESS CHANNEL STEAMER WITH STEAM TURBINES OF 50,000 I. H. P. DISPLACEMENT 1300 TONS

few months previously in the trials of the torpedo boat *Daring* by Mr. Thorneycroft and Mr. Barnaby, and named "cavitation" by Mr. R. E. Froude, F. R. S.

A radical alteration was deemed absolutely necessary. A new turbine engine was made, consisting of three separate engines,—high-pressure, intermediate-pressure and low-pressure,—each of which drove one screw shaft.

The power of the engine was thus distributed over three shafts instead of concentrated on one, and the arrangement of three propellers on each shaft was adhered to.

The result of these changes was marvellous. The little vessel now nearly doubled her speed; 30 knots were soon reached, and finally 32¾ knots mean speed on the measured mile authenticated, which made her the fastest vessel afloat, irrespective of size.

Not only was she the fastest vessel, but at all speeds vibration, which is so pronounced in all fast vessels, especially in torpedo-boats and torpedo-boat destroyers, was entirely absent in her case. But more important still was the remarkable economy of her engines, for when subjected to numerous exhaustive tests by Professor Ewing, F. R. S., and Professor Dunkerley (now of the Naval College, Greenwich), the consumption of steam per indicated horse-power for all purposes at 31 knots speed was found to be 14½ pounds; or, in other words, with a good marine boiler, the coal consumption would be considerably under 2 pounds per indicated horse-power,—a result better than is obtained in torpedo-boats or torpedo-boat destroyers with ordinary triple expansion engines.

The vessel's reversing turbine was also altered, giving her an astern speed of 6½ knots; it could bring her to rest in 36 seconds when running at 30 knots speed, and from rest she could be brought up to 30 knots in 40 seconds.

THE "TURBINIA." LENGTH 100 FEET. PROPELLED BY STEAM TURBINES OF 2000 H. P.

The *Turbinia* cruised from the Tyne to the naval review at Spithead, where, after making many fast runs in the Solent, she steamed on the day of the review (at the request of Prince Henry of Prussia) at a speed of 34½ knots, and in the painting of the review by Signor de Martino for the Queen the *Turbinia* figures conspicuously in the foreground.

These results may be said to have been obtained without a very abnormal performance as regards the boiler. Its total heating surface is 1100 square feet,

and it was forced to an evaporation of about 30 pounds per square foot at the speed of 34½ knots; but it should be noticed that the relative heating surface to total weight of boiler is abnormally small. This arose from the boiler having been originally fitted with a large superheater with a total surface of one-half that of the boiler proper. This superheater was found to be unsatisfactory and unmanageable, and, after the earlier trials, was removed.

Recently trials were made to test the endurance of the machinery, and these showed that, with a clean bottom, the boat can maintain a speed of over 30 knots for three hours. The condenser, it is true, is abnormally large, possibly too large,—in the recent boats it is smaller,—but a vacuum of about 27 inches is obtained, and the excellent results of economy in the turbines seem to have justified some departure in this respect from the usual proportions in marine practice. The small weight of the engines and their economy in steam are, however, alone responsible for the abnormal results obtained. The leading particulars are:—

Main engines	3 tons 13 cwts.
Total weight of machinery and boiler, screws, shafting, tanks, etc	22 "
Weight of hull	15 "
Coal and water	7½ "
Total displacement	44½ "

The object of the Pioneer Syndicate having been attained, a company called the Parsons Marine Steam Turbine Company, at Wallsend-on-Tyne, England, was incorporated under the same directorship for applying the steam turbine system commercially to all classes of fast vessels. Large shops, capable of manufacturing about 150,000 H. P. of turbine engines per annum have been erected at Wallsend-on-Tyne, and a destroyer,—the *Viper*,—fitted with turbine engines of 12,000 H. P., is being built there for the British Government, and another set of engines of equal power is being supplied to Sir W. G. Armstrong, Whitworth & Co., Ltd., for one of their destroyers.

Both these destroyers will shortly be put to trial, and it is anticipated that the guaranteed speed of 35 knots will be considerably exceeded. The saving of weight is remarkable, as compared with ordinary engines for this type of vessel, the horse-power per ton of total weight of machinery, including boilers in working trim, being 75 with turbine machinery, as compared with 48 with ordinary engines and the same class of boilers. The superior economy in steam permits of a larger horse-power from the same boilers, and also, owing to the lesser weight of the engines, of larger boilers, and consequently a much greater total horse-power per ton on a given displacement.

It is a feature of turbine engines that the larger the scale on which they are constructed, the more marked are their advantages as to bulk, lightness, economy and simplicity.

The upper illustration on page 200 shows a cross-Channel boat for 30 knots speed. There is ample accommodation, all the machinery being below the main deck, and the passengers are sheltered from the wind and spray by the upper awning deck of light steel.

The lower drawing shows a cross Channel boat of similar design, to make the passage of 22½ statute miles from Dover to Calais in under half an hour, or from Newhaven to Dieppe, 75 statute miles, in one hour and forty minutes. The vessel is 1300 tons displacement, and the engines and boilers are of 50,000 H. P., the boilers being of the latest express water-tube type.

The speed for long voyages is limited by the amount of coal that can be carried, but turbine engines, from their lightness and economy in steam, present considerable advantage to the naval architect in machine designs for fast Atlantic liners. Still, there is no question that the highest speeds will be reached in the case of short-passage vessels and where time is of considerable importance.

In such vessels only a comparatively small amount of coal storage is necessary, and when the bulk of the passenger traffic is sufficient to justify the greater expenditure, such fast turbine

propelled vessels will undoubtedly be adopted.

In conclusion, it may be interesting to give a few particulars as to what may ultimately be reached in fast speed, unarmoured cruisers of moderate size, though, doubtless, it will take some courage to enter upon the construction of such a vessel. Still, something like this will probably be attempted before long,—a vessel of 3000 tons displacement, 450 feet in length, 42 feet beam and 14 feet maximum draught of water, carrying turbine engines and boilers of 120,000 maximum horse-power, the boilers being of the water-tube type arranged in two tiers.

This vessel could steam economically at 16 knots speed, but would, in emergency, be capable of increasing her speed to 48 knots and maintaining this speed for three hours; or she could maintain a speed of 45 knots for eight hours. She would be difficult to hit with shot, and her speed being 18 knots greater than that of any locomotive torpedo, she could well take her chance in this respect. A few such vessels would be of immense tactical value to a squadron in time of war.

THE INFLUENCE OF MOTIVE POWER ON THE DESIGN OF COTTON MILLS

By Stephen Greene

IN a paper read recently before the New England Cotton Manufacturers' Association, the writer undertook to deal briefly with the subject of modification in mill design resulting from changes in motive power. For this purpose the history of mill designing was considered as divisible into three general periods. These divisions may not be so clearly marked as to stand out distinct from one another; on the contrary, from the nature of circumstances, they run into and lap over one another; but still the division may be made in a general way.

The first period may cover the time from the beginning of the factory system up to the time of the general introduction of the modern automatic cut-off steam engine, which date may be placed about 1860. The second period may be taken as extending from the date just given to about 1893, when electric transmission began to be seriously considered in the driving of textile mills.

In the first period water power in its various stages of application was the ruling factor in motive power for textile mills. In the second period the steam engine disputed the sway of the water-wheel and succeeded in taking the primary rank. We are just upon the threshold of the third period, and a large part of what may be said must be regarded in the light of prophecy and not history.

In the early days of the factory system the water power was in a large degree the controlling factor. The mill was located with reference to the water power, and the particular development of the power in hand controlled in a very large measure the design of the mill structure.

It has always been considered of prime importance in designing transmission of power, that the drive should

be as direct and short as possible. In the days of the water-wheel, when the breast and over-shot pattern of wooden wheels was in vogue, it seemed a necessity to so place the wheel with reference to the mill that short lines of shafting could be used. It was, therefore, the common practice to place these large wooden wheels at the centre of the mill, even though the building was a very small one, and then, by vertical shaft and gear connections, and a little later by a belt connection, to transmit this power from the wheel, located at the centre and in the lower part of the building, to the upper stories.

The topography of the site, together with the desire to secure economical power transmission from wheel shafts of low velocity, led the mill engineer to design buildings of considerable height and not covering a great deal of ground surface.

It is exceedingly rare to find a water-power development where the fall is of any considerable height, that affords a location for a mill, with a suitable and economical development of the power, that is so nearly level as to avoid one or more basements. It was frequently the case that two and even three full stories were built below the grade of the yard in the front of the mill, necessitating the lighting of this floor space from one side only.

The introduction of the modern turbine wheel, together with the demand for larger plants, marked a step in advance in mill design. It was found possible to place the wheels in such a position as would best suit the peculiar development of that power, and then to transmit the power through gears and shafting to some central point of distribution in the mill.

This gave an opportunity for a little freer development of mill design, in that more attention could be given to the exact requirements of the machinery and the organisation of the mill, and less attention to the particular relation of the power plant to the machinery.

Quite a number of mills are now in existence, or were within a few years, where the change had been made from the old-fashioned breast wheel to the modern turbine wheel; but the design of the buildings gave clear evidence of the limitations that were imposed by the type of water-wheel in use when the mill was actually constructed.

With the advent of the automatic cut-off steam engine with which the name of Corliss is indissolubly connected, the field was opened for a still further modification of mill design. It was no longer necessary to select a site by the river bank where the topography was more characteristic for its beauty than for its utility; but a spot could be chosen where a mill could be built much more economically, and where the requisites of light and ventilation could be met in a much more satisfactory manner. The topography of the site selected, without regard to motive power, may determine in a large measure the design of the building, and inasmuch as the change from water power to steam power allowed a freedom of choice in the matter of site, the simple change from water power to steam exerted great influence in the modification of mill design.

In the early practice of transmission of power from steam engines, when slower speed of shafting was in practice, it was thought necessary to place the engine near the centre of the building so that the transmission of power might be attended with the least possible loss; but as higher speed of shafting became common, and more perfect construction in the bearings and couplings became possible, less objection was found to long lines of shafting, and in order to secure less interference with the machinery in the mill the practice finally prevailed of placing the engine near one end of the mill, and transmitting the power from the engine to the main shafts by belts or ropes located in a tower.

It may be stated at this point that the improvement in water-wheels, and the adoption of horizontal wheels has rendered possible, in the case of water power mills, a proportion at least of that freedom in design which is more characteristic of the steam power mill.

The horizontal wheel with the draught tube enables the mill engineer in many cases to place the wheels where the best results can be obtained, and, at the same time, with slight loss in transmission of power, place the building on a much more desirable site for the mill than was possible where the old type of wheels was used.

It is, therefore, evident that the first two periods referred to in this article may not be distinguished absolutely as the water power period and the steam engine period, for the improvement in water-wheel design has furnished opportunity for a greater freedom in mill designing, in some cases approaching that of a steam power mill.

It still remained true, however, in the second period, if the desire was to use water power, that the mill must be located in the immediate vicinity of the water power development. If steam was to be the motive power, it was desirable to locate the mill building at a point where the fuel could be delivered at an economical cost.

The introduction of the electric generator and motor, at first regarded as the toy of the theorist, and a little later as a luxury to be enjoyed by those who had money to throw away, was the sure prophecy of a complete revolution in the design of textile mills.

At last it seemed possible to select a site that should be most convenient for the essential requirements in manufacturing, viz., the securing of labour, raw material, and transportation of the finished product at a minimum of cost, and to erect a building that should be exactly adapted to contain the required machinery, arranged in the best possible manner to fulfill its functions.

The possibility was seen and recognised long before the actual realisation was possible, for while it was theoretically possible to transform the mechanical energy of a water power or steam engine into electric power, and then conduct this power through copper wire to a motor located at the point of distribution of power, the cost of such apparatus, together with the heavy loss in transmission, was an effectual barrier to its adoption in any large degree.

Fortunately, the study of electrical transmission and the perfection of the apparatus was entered upon and pursued with such perseverance and success that we have already reached the point where it is not simply theoretically possible, but practically advantageous in many cases to locate the mill at the best possible point as concerns the design of the building and the organisation of the machinery, and utilise the power at any considerable distance from the mill.

It would seem, therefore, that under certain conditions the mill designer may be free from the limitations of the location of motive power in the immediate study of the design of the building and location of machinery.

It has already been stated that in dealing with this third period we must necessarily treat, in a large measure, of possibilities and not of actual experience.

It is, perhaps, impossible for any one to prophesy the rate of development along the lines indicated. It can hardly be claimed with justice that at the present time the electric transmission of power has reached such a state of development that it is applicable in all cases. It is, undoubtedly, true to-day that if a site could be selected and the source of motive power, either the water-wheel or the engine, so arranged that the power can be transmitted from the wheel shaft or the engine shaft, as the case may be, directly to the main shafts in the various departments of the mill, no saving, either in the fisrt cost of installation or the economy in running, would be experienced by substituting electrical transmission for mechanical transmission.

While this is true so far as a textile mill is concerned, where the load is practically constant throughout the sixty hours of the week, it would not hold in the case of manufacturing plants of other types where the load is not constant, and where different departments are likely to be run with varying loads and at different times. Under

such conditions the time for the adoption of electrical transmission has already come.

There may also be cases where existing plants are so scattered, covering such an area, that no central power plant can furnish the power with mechanical transmission, with any good degree of economy, so that electric transmission is practically applicable.

In view, however, of the remarkable advance that has been made in a very few years, it is not difficult to imagine that before many years have elapsed it will be perfectly practicable and a positive advantage, even though the site may allow placing the motive power immediately within the building, that the power shall be transmitted to the various parts of the building by electric transmission, thereby modifying, in a marked degree, the design of the mill organisation.

As an illustration of the possibilities in this line of development, reference may be made to the mill recently erected by the Pelzer Manufacturing Company at Pelzer, S. C., U. S. A. The company had three mills containing in the aggregate 50,000 spindles, and grouped about the mill was the village with tenements, schools, churches, stores, and other conveniences for the operatives. The company desired to extend their plant, and in anticipation of this had purchased a large tract of land with water power, some two miles and a half below the original mills.

Their plan was to erect a mill at the site of the water power, but it was found that such a location would involve expensive foundations and a large outlay to render the site available for a large mill.

After a careful study of the question, it was decided to develop the water power at the most available point and erect the mill near the original mills on a site which was peculiarly advantageous so far as construction was concerned, and transmit the power by electric transmission from the water power two and one-half miles below, to the mill.

By doing this the cost of constructing the mill building was not only very much less, but many of the advantages of the town already in existence were available for the new mill, and the expense of a railroad to the lower site was avoided.

It is not claimed in this paper that at the present time electric transmission is universally applicable, but it may be claimed with propriety that under certain conditions the advance in the manner of transmitting power has made it possible to exercise much greater freedom in designing and organising the modern cotton mill.

ELECTRICITY IN MARINE WORK

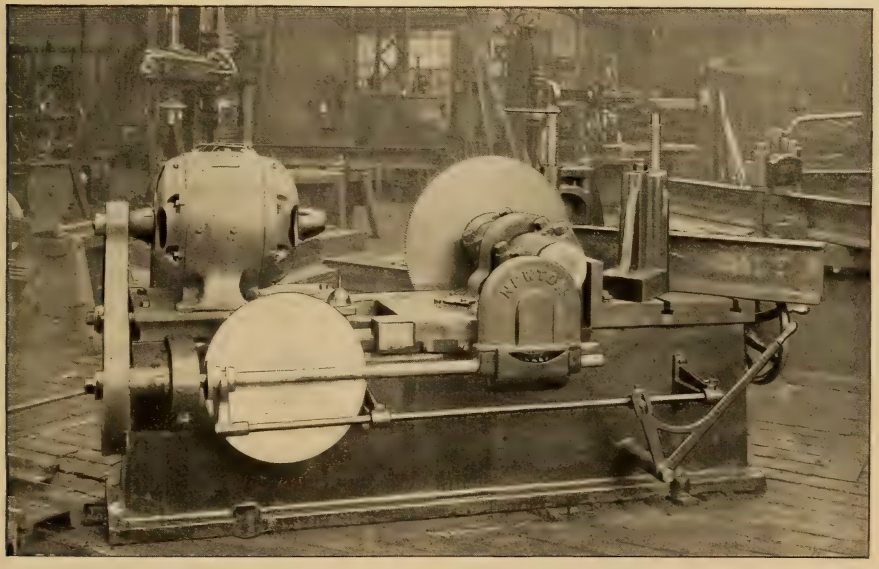
ITS GROWING APPLICATION IN THE UNITED STATES

By S. Dana Greene

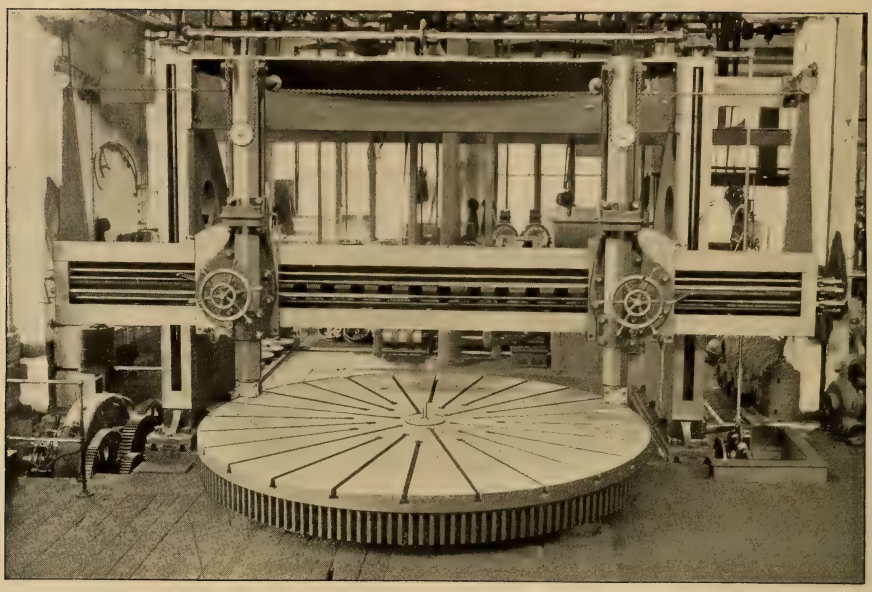
ELECTRICITY has ceased to be a plaything or an experiment in marine work. It is slowly but surely finding its place in the shipyard and aboard ship, not because it is novel and interesting, but because conservative men find that it pays as an investment; and this is the only final and proper test by which to judge the success or failure of a new form of power.

The conditions, however, affecting the use of electricity ashore and afloat are quite different, and it does not follow necessarily, because it has been tried successfully where the ship is built, that it will be equally successful when used on board the ship itself. We must, therefore, consider the two cases separately, each on its own merits.

Taking up first, then, the shipyard, we find that, in introducing electricity for transmitting and utilising power for various purposes, shipbuilders are following the precedent established by many of the leading manufacturing establishments. The central power stations now established in nearly every city and town, where electricity is generated and from which it is transmitted for lighting and for the operation of street cars and motors of all kinds, are as familiar as the water reservoir or the gas works; but it is not generally known

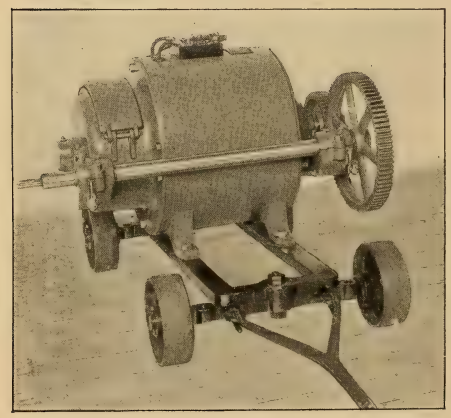


AN ELECTRICALLY DRIVEN COLD SAW FOR SHIPYARD SERVICE



AN ELECTRIC BORING MILL, SUITABLE FOR SHIPYARD WORK

that many isolated manufacturing plants are to-day operated in part, or in whole, by electricity, the change in motive power having been rapid in the past five years. Among them are steel works, agricultural and electrical machinery works, and woolen and cotton mills, covering from 50 to 150 acres of ground, and employing from 3000 to 10,000 operatives, the power ranging from 1000 to 5000 H. P. or more, distributed over many buildings and divided into units of all sizes, from one horse-power to five hundred.



PORTABLE MOTOR FOR SHOP OR YARD WORK

The problems of lighting and heating, and of furnishing the necessary power for such plants, are very serious, involving a heavy capital expenditure and very large operating expenses. It is not too much to say that the cost of any other power than electricity would be considered prohibitive for a new plant of this kind to-day, and old plants are changing to electricity as rapidly as possible. The present practice is to confine the generation of the power to a central plant, as is done in a city power plant.

The "prime movers" may be large, economical steam engines, or perhaps water-wheels, located at a water power many miles from the manufacturing plant. Electric generators of proper size (five hundred to one thousand horse-power) are connected direct to the shafts of the engines or water-wheels, and from these the electric current is transmitted by proper conductors, placed either overhead, or preferably underground, to the various shops where it is used, as required, for lighting and for driving individual tools, or

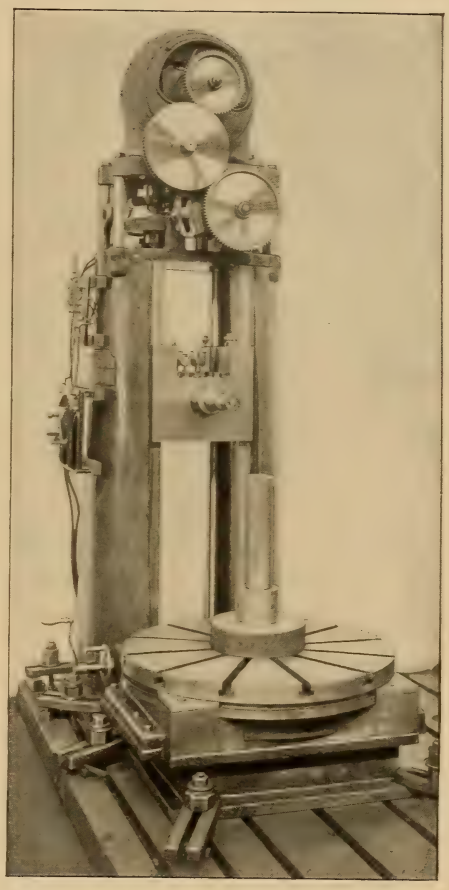
lines of shafting. In addition, electric motors are utilised to drive ventilating fans,—a necessity in many shops,—and the exhaust steam from the main engines furnishes an admirable system of low-pressure heating in cold weather.

The cost of producing this power is probably less than twenty-five per cent. of the cost of any other form, while its flexibility, cleanliness, low fire risk and economy of application are incomparably superior. A conservative estimate of the large manufacturing establishments in the United States, using electricity for operating their plants, places the power at 200,000 horse-power, which represents a capital outlay in engines, boilers, generators, motors and accessories of about $20,000,000 (£4,000,000). There are, moreover, now in contemplation new installations, or additions to old ones, which will probably aggregate as much or more.

The growth of modern steel shipbuilding in the United States has been very rapid in the past ten years, and as the shipyards have increased in size and in the volume of their work, the problem of economical power generation and distribution has required close attention. The result has been the introduction of electricity, not only in private shipyards, but also in the government navy yards which never adopt a modern improvement until its success has been thoroughly assured.

The shipyard, however, presents some new problems not encountered in the ordinary manufacturing plant, for power is required not only in the shops where regular machine work of all kinds is done, but also for the large derricks and traveling cranes in the yards, an extensive system of tramways, portable drills and other tools for use on the hulls, temporary lighting of the hulls, pumps for dry docks, and for various other purposes. Appliances, like those mentioned, must be ready for use at any and all times and in different parts of the yard. Furthermore, shipyards, with the exception of those on the Great American Lakes, are located on salt water, and as many of these appliances must operate out of doors, the motors and the conductors leading to them must be properly protected from salt air and from the weather.

While this necessitates special precautions in these cases, it cannot be said that such applications are experimental, for no service in a shipyard can equal in severity that imposed on a



AN ELECTRICALLY DRIVEN MILLING MACHINE

street car motor, for example, which is operated by a man who does not see it, and who knows little or nothing of its construction or care. It is, besides, necessarily exposed in its location under the car to all kinds of weather conditions under the most unfavourable circumstances. In spite of these difficulties, there are more street car motors in use to-day than motors of any other single

A 150-TON ELECTRICALLY OPERATED REVOLVING DERRICK IN THE YARD OF THE NEWPORT NEWS SHIP BUILDING AND DRY DOCK CO., NEWPORT NEWS, VA.

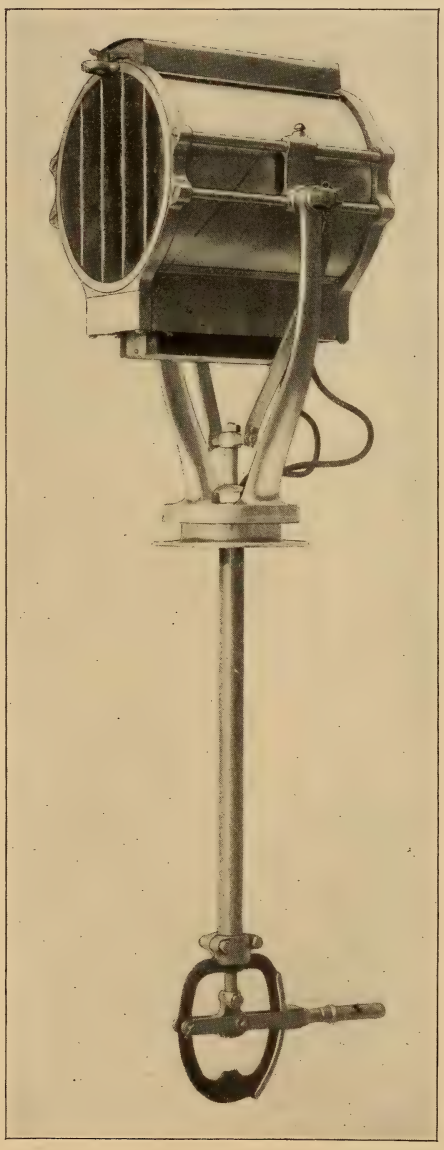
type built. The distinguishing features of such a motor are its generally massive construction, ample bearings, large reserve capacity, and an enclosing steel case, itself a part of the structure, which protects the more delicate parts and renders the motor practically dust and water-proof. Such a type lends itself readily to many of the out-of-door requirements of a shipyard.

One characteristic of the electric motor is its continuous and uniform rotary motion as distinguished from any motor in which the rectilinear motion of a piston, whether actuated by steam, gas or compressed air, must be converted into rotary motion before it can be utilised. This advantage of the electric motor does away with vibration and the resulting necessity of expensive foundations, reduces the weight for a given power, and renders its application to almost any work a simple problem mechanically. Such simplicity insures smooth and quiet running, low maintenance cost, and a minimum of attendance.

Before the general introduction of electricity in shipyards it was customary to use compressed air for operating riveters and drills, and for other out-of-door work. This not only necessitates an expensive plant for compressing and storing the air, but permanent pipes must be laid wherever the power is required, and flexible pipes must be used in the vicinity of the work. The system is cumbersome and expensive, both in first cost and in operation, while not over 10 to 15 per cent. of the power generated by the engines driving the compressors is realised in effective work.

With electricity, the operating cost is greatly reduced, while an efficiency of from 60 to 70 per cent. is realised in the system. This, of course, means a smaller plant for a given amount of work, and, therefore, a lower first cost of installation.

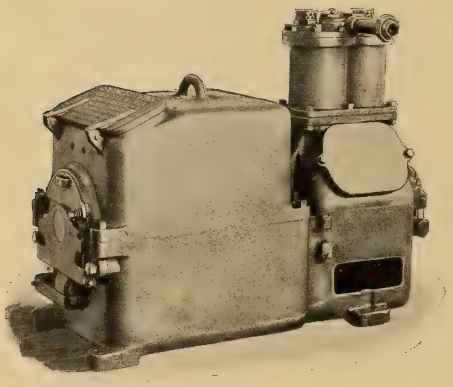
A typical application of the electric motor was recently completed at the shipyard of the Newport News Shipbuilding and Dry Dock Company, at Newport News, Va., U. S. A., for the operation of its 150 ton jib crane, the largest of its kind in the world, and a brief description of it is interesting and instructive, not only on account of its size, but also because it is fairly representative of the best practice of the modern well-equipped shipyard. The fundamental requirements, briefly stat-



SEARCH LIGHT

ed, were capacity to lift and place on board the heaviest single weight liable to be encountered in the probable development of modern ships; a field of operation as large as practicable in which these weights could be handled, and absolute precision within this field; a location accessible by the ordinary means of transportation from all parts of the yard; and, finally, that greatest factor, defined in all projects by the broadest use of the word economy.

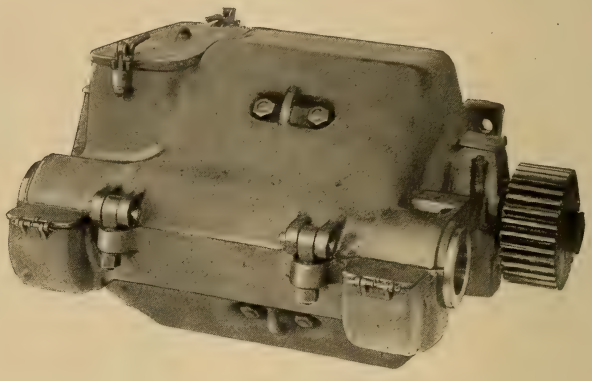
The question involved in the choice as to the form of energy to be employed in such a machine cannot be fully discussed here, but the convenience of operation, ease of movement and general efficiency of the present derrick attest the successful use of electricity in this case. Current is transmitted, over heavy insulated copper wires, to fixed brushes, attached at the centre and near the top of the steel tower. These brushes are arranged to bear against circular contact rings insulated from, but carried by, the centre casting to



AN ELECTRIC AIR COMPRESSOR FOR SHIPYARD USE

which the roller rods are secured. Near the top of this casting are two more contact rings which transmit the current to a pair of brushes, fixed to the revolving part of the derrick, from which the current is delivered over heavy insulated copper wire to the several motors. The current thus delivered, under normal conditions, is at a pressure of 220 volts.

With the outer end of the jib in its lowest position, the hoisting blocks will, on rotation of the derrick, describe the circumference of a circle 207 feet in diameter; with the jib at its highest position, these blocks, on rotation, describe the circumference of another concentric circle, 88 feet in diameter, thus permitting the derrick to operate on weights lying anywhere within the circle ring whose maximum and minimum diameters are 207 feet and 88 feet, respectively. The maximum load of 150 tons can be handled only within a ring whose maximum and minimum diameters are 147 feet and 88 feet, respectively; but weights up to 70 tons may be handled throughout the entire field of operation.

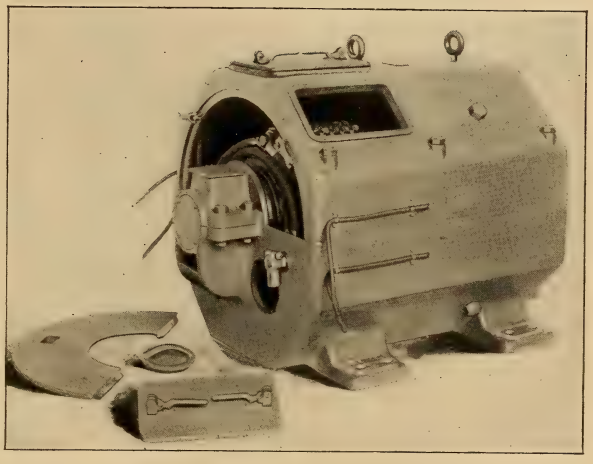


AN ENCLOSED TYPE OF MOTOR FOR GENERAL OUT-OF-DOOR WORK

This feature of varying the radii at which the hoisting blocks can operate constitutes a most important difference between the derrick under discussion and the 130-ton steam crane erected in 1893 on Finnieston Quay, Glasgow. In the Finnieston crane, which, at the time of its construction, represented the ideas of best British practice, there is no variation in the radius at which the hoisting blocks are carried, and, in consequence, the field of operation becomes narrowed to a single line, the circumference of a circle described by the blocks on revolving the crane. The advantages of the Newport News der-

rick are obvious. The maximum elevations, above mean high water, for the hoisting hooks in the high and lower positions of the jib are 118 and 69 feet, respectively, this giving ample clearance vertically for any probable conditions.

The motors and controllers used for the three motions required,—that is, the revolving of the derrick, the raising or lowering of the jib, and the hoisting of weights,—are all of the street railway type, and the complete installation, which was undertaken by the General Electric Company, of New York, has been most successful. Its distinguishing features are noiselessness, the comparatively small amount of power required, and the general economy of operation. The illustrations give a good idea of the motors and controllers used, as well as of the crane itself. There is also shown a travelling crane of cantilever construction, electrically operated, which was recently installed at the same yard.



A TURRET-TURNING MOTOR ON THE U. S. BATTLESHIPS "KENTUCKY" AND "KEARSARGE"

Summarising the work already done in the introduction of electricity in government and private shipyards, it may be said that about 5000 horse-power of apparatus, representing an investment of about $750,000, has already been installed in the United States, and the satisfactory results attained indicate that this work will be extended and amplified as circumstances permit, until every yard is completely equipped with the electric drive.

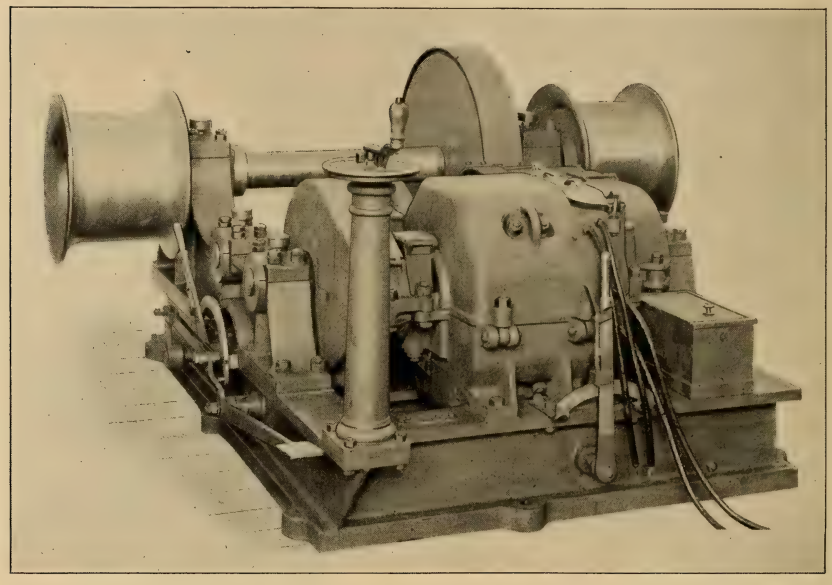
Turning now to the ship, we find new and complicated conditions for electricity to meet and overcome, and for many years, after such installations on shore lost their novelty, these conditions served as effectual bars to similar installations afloat. A ship at sea is a small world in itself, in which several hundred people must live and work together for weeks or months at a time, having little or no communication with the outside world, and relying necessarily upon what is in the ship for their maintenance as well as for the tools to perform their daily duties. Under such circumstances, it is not surprising that sailors are notoriously conservative about the introduction of new appliances aboard ship; for if these should fail in the middle of a long voyage, when facilities for repairs are not at hand, the lives of the passengers and crew, or the safety of the ship itself might be seriously jeopardised.

It was many years after the introduction of steam as a motive power before it was considered safe to dispense entirely with sails, and the substitution of machinery for hand power in the manipulation of the various auxiliaries of a ship has been largely accomplished within the past twenty years. The sailor at first looked upon electricity with suspicion as a new and untried form of power for ship work, and electricians on shore, while they believed that its introduction aboard ship would prove simple and economical, were, nevertheless, generally unfamiliar with the conditions of sea life.

They did know that three great enemies of electrical apparatus, salt air, moisture, and heat, were always present, and they were afraid of them. But the many obvious advantages of the electric light aboard ship gradually

overcame the sailors' conservatism and the electricians' fears, and lighting plants are common to-day in every well-equipped vessel, in spite of numerous troubles experienced at first, both with the apparatus and the electric wiring.

In a modern plant of this kind, the electric generators of the multipolar



AN ELECTRIC DECK WINCH

type are coupled direct to vertical engines, either simple or compound condensing, there being several such units, or sets, as they are called, for regular operation, as well as one or two spare units which are held in reserve. The set is compact, economical in space and weight, and operates smoothly and quietly with excellent economy. The bearings are large, and the engines are thoroughly lubricated by a system of forced oil circulation.

Every square foot of space and every pound of weight must be used economically on board a modern vessel, and these generating sets are models in this respect. They are usually located in or near the engine and boiler room spaces; on a man-of-war they are always considered as one of the vitals of the ship, and, as such, are placed in a separate compartment below the protective deck, which covers and protects boilers, engines and magazines. If the steam turbine, which has given such remarkable experimental results in the little 100-foot *Turbinia*, and which is about to be tried on a larger scale by the British Admiralty in one of its new torpedo-boat destroyers, should prove economical and reliable in service, its use for direct coupling to generators will lead to a marked reduction in space and weight of marine sets; for the turbine, unlike the ordinary steam engine, has a continuous rotary motion and runs at a relatively high speed. For a given output it is much lighter and smaller than the reciprocating engine. Then, too, the size and weight of an electric generator vary almost inversely as its speed of rotation; if, therefore, a satisfactory "turbo-generator" unit can be produced, running at about 1800 revolutions a minute, instead of at about 400, as at present, the size and weight of the combined unit will be probably less than one-half that of the present standard, and the fact that there is no

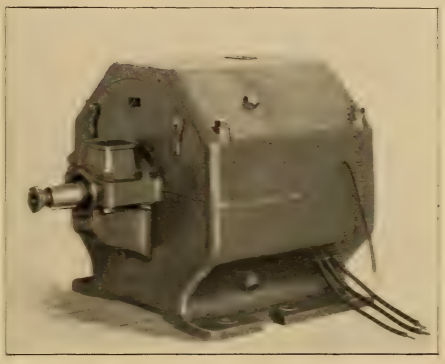
vibration,—a necessary evil with reciprocating engines,—will render heavy supports and foundation plates unnecessary.

From the generators the current is carried to suitable switchboards, made of slate or marble, and located usually in the dynamo room, and from these it is distributed through suitable switches, protective safety devices, and measuring instruments, to the copper conductors running to all parts of the ship

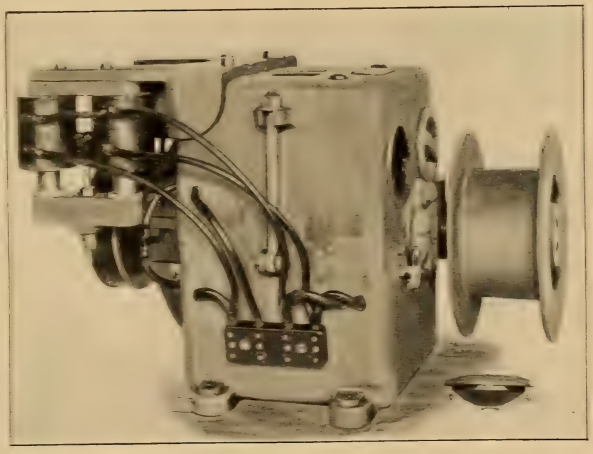
These conductors are most carefully insulated with heavy rubber coverings, and protected from mechanical injury by running them in iron pipes, which are built into the ship and japanned on the inside to insure a smooth surface, or by inclosing them in heavy wooden mouldings secured to the deck beams overhead. On the spar deck, where lamps and fittings are exposed to the weather, and in the engine and boiler rooms and coal bunkers, where they may be exposed to heat, oil, steam, or coal-dust, they are made water and dust-tight by suitable rubber gaskets and bushings, the lamps themselves being inclosed in an outer globe, protected by a heavy metallic guard.

The most important lights aboard ship are the so-called "running lights," the familiar red and green side lights and the white masthead light, seen on all moving steamers at night. The international "rules of the road" require that these lights shall always be shown, and in order to provide against the danger of one of them being accidentally extinguished, each lantern with its heavy ribbed glass lenses of proper colour is fitted with two incandescent lamps, only one of which is normally in operation. If it fails, a a warning bell sounds in the pilot-house, thus indicating that the first lamp has been extinguished.

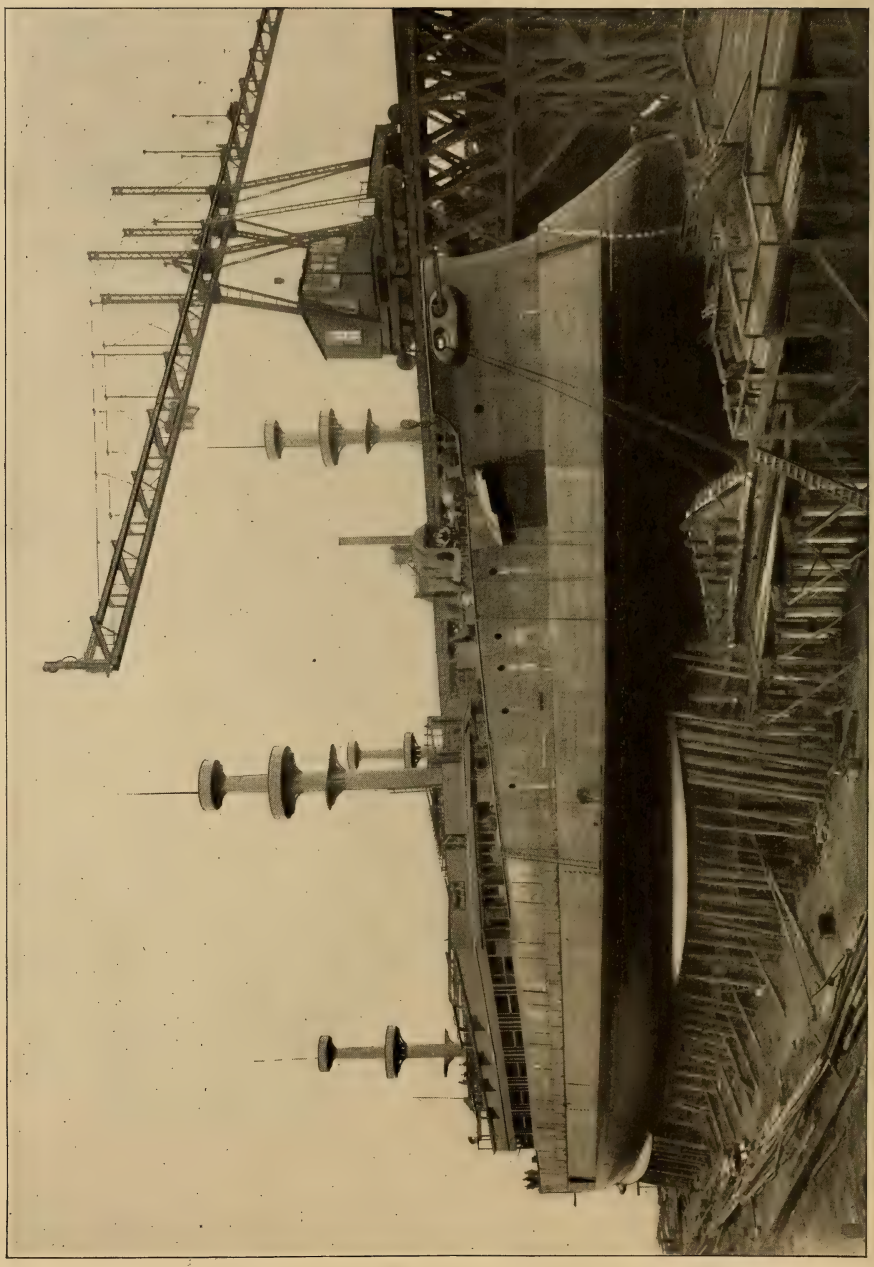
The reserve lamp can be switched in and the regular lamp replaced by a new one. In the United States Navy, as well as in other navies, night signals are made by electric lights. Four double lanterns are hung on a jack stay in a vertical line from the masthead, about twelve feet apart. Each lantern is divided into two compartments, having an upper white lens and a lower red lens, with a thirty-two candle-power incandescent lamp mounted in each compartment. From each lantern conductors are led to a keyboard, somewhat similar to a typewriter board, and by pressing the proper keys, any given combination of red and white lights can be displayed, each lantern showing one colour only for any given signal. The



A BOAT CRANE MOTOR



AN AMMUNITION HOIST MOTOR

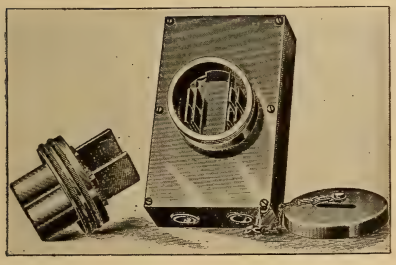


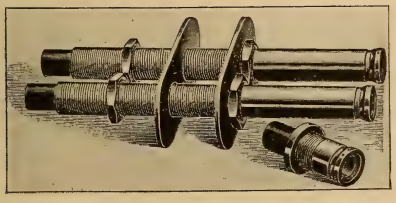
AN ELECTRICALLY OPERATED CANTILEVER CRANE IN THE YARD OF THE NEWPORT NEWS SHIP BUILDING AND DRY DOCK COMPANY

signal is read from the top down, and each letter of the alphabet and each numeral from zero to ten is indicated by a certain combination.

The ship receiving the signal repeats it as it is displayed by the signalling ship, or it may simply acknowledge each word, to show that the letter or word is understood. This system, for distances up to three or four miles, works admirably, and is incomparably superior to any other yet devised. It was used extensively by the United States fleets during the late war with Spain, and the celerity with which signals were transmitted and received with a little practice was remarkable.

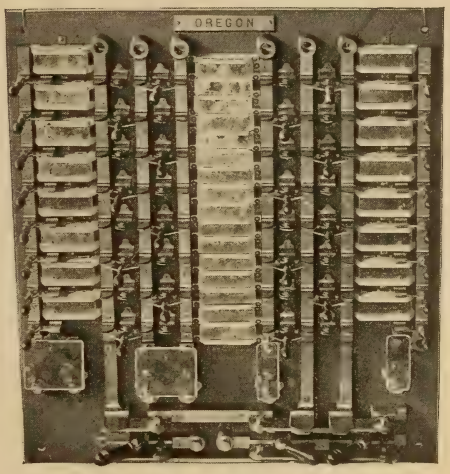
The familiar street arc lamp, fitted with proper globes and guards, is now being introduced on cargo vessels, for use in loading and unloading at night. Some of the colliers sent to Cuba to supply the American vessels with coal during the war were supplied with these lamps, and their intense illuminating power, as compared with the incandescent lamp, greatly facilitated the coaling of ships at night. When a thousand





SOME WATER-TIGHT ELECTRIC WIRING FIXTURES

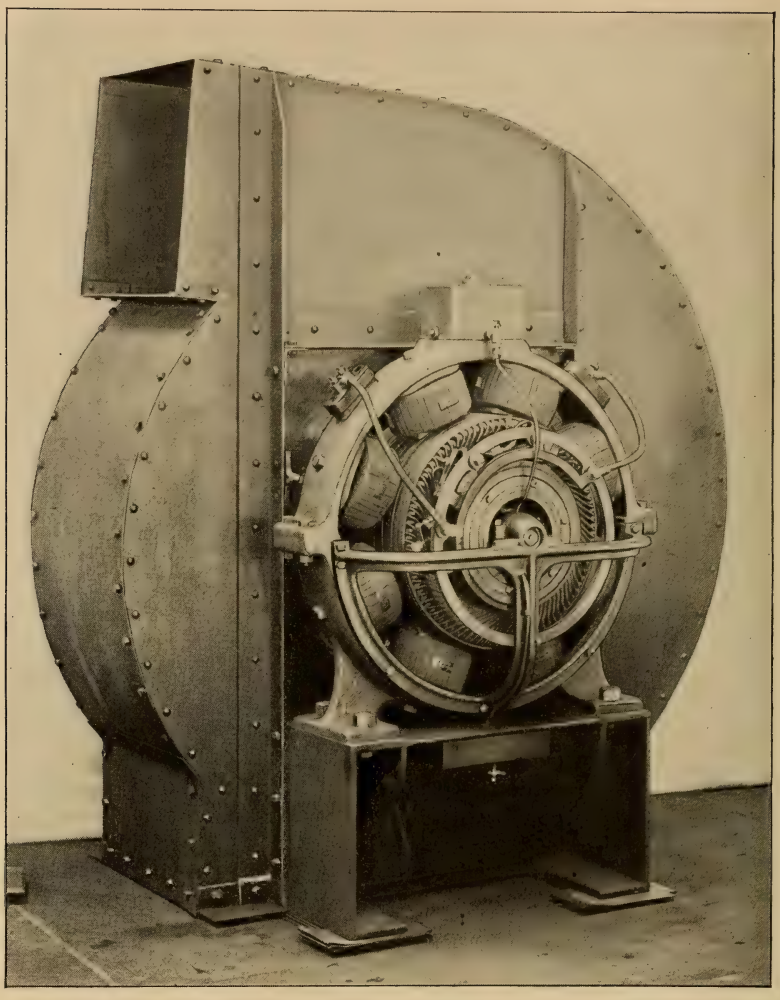
tons, or more, of coal must be loaded on a single vessel, the rate of loading being from 200 to 300 tons in twelve hours, the importance of night work under such conditions is apparent. The importance of searchlights aboard ship, both from a military standpoint



A UNITED STATES NAVY SWITCHBOARD

and as an aid to navigation, has become generally recognised. The use of such lights by Admiral Sampson's fleet while blockading Santiago is still fresh in the public mind. The beams from these searchlights were so powerful and so well directed on the entrance of the harbour that it was impossible for a row-boat to show itself without discovery, to say nothing of one of the Spanish torpedo-boat destroyers or larger vessels.

The searchlight is also used for navigation purposes at night on many American coasting steamers and on the inland rivers and Great Lakes of the United States, where narrow and tortuous channels must be navigated. Buoys and range marks can be readily picked up, and landings made, which would otherwise have to be deferred until daylight. The Providence and Stonington line of steamers, running on Long Island Sound, have used the searchlight with considerable success as a fog signal in the fogs which are of frequent occurrence on that body of water. The beam from such a light has little or no penetration in a fog, but if it is thrown into the space above and ahead of the vessel, it makes a luminous spot

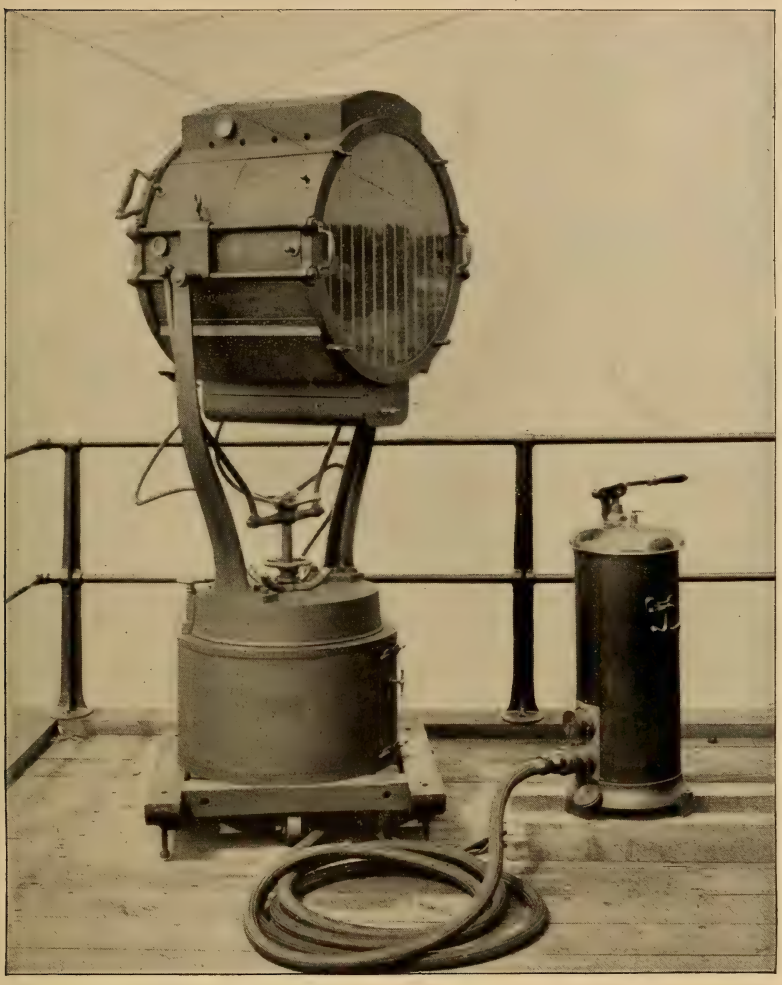


A 50-INCH ELECTRICALLY DRIVEN BLOWER

in the fog which can be distinguished by other vessels at a distance of half a mile or more, thus enabling them to avoid the vessel carrying the light. Any one who has had experience at sea, and who knows how difficult it is to locate an approaching vessel in a fog by the ordinary fog signals, will appreciate the advantage of even a rough indication of the vessel's position when still half a mile distant.

The introduction of electric lighting aboard ship has added materially to the health and comfort of passengers as well as crews, and has also proved an aid to navigation and a distinct military advantage to war vessels. These advantages, however, are of minor importance compared with those to be derived from a general use of electric motors for driving the various ship auxiliaries. Few people, outside of those professionally interested, realise that on a modern steamship of 8000 or 10,000 tons displacement, there are forty or fifty auxiliary engines, besides the main engines of the ship.

These auxiliaries are scattered all over the vessel and aggregate a thousand horse-power or more. They in-



AN ELECTRICALLY CONTROLLED SEARCH LIGHT PROJECTOR, MADE BY THE GENERAL ELECTRIC CO., NEW YORK

clude the anchor engine in the extreme forward part of the ship and the steering engine in the extreme after part; the boat cranes and deck winches on the upper deck; the ice machines, ventilating fans, ash hoists, dynamo and workshop engines on the intermediate decks; and the numerous pumps required in the boiler and engine rooms, as well as those located elsewhere for fire purposes and for freeing the ship from water. On a war vessel, there are, in addition, the necessary engines for turning the turrets and manipulating the heavy guns, and also the hoists for powder and shell.

Steam has been generally used for the auxiliaries, first, because the boilers of the ship are always available for furnishing the necessary power; and second, because small steam engines and pumps have been so well developed and so long in use that they have become familiar to the sailor and lend themselves, by reason of their substantial construction, to the rough usage of ship work. The use of steam, however, involves the running of miles of pipes through the ship, heating all living spaces to an uncomfortable degree; demanding constant inspection and repairs to overcome leaky valves and joints and presenting a menace to life,

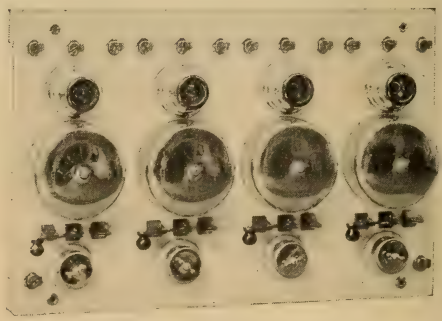
particularly on a war vessel, by a possible breaking or bursting. There is, besides, a considerable loss of power in such a system, due to leakage and condensation, and the auxiliaries themselves are very uneconomical in operation.

AN ARDOIS SIGNAL SET

The economy of the auxiliaries has not received, until recently, the attention it deserved, but a paper published about a year ago on the performance of the United States cruiser *Minneapolis* during a week's run from Gibraltar to Philadelphia, has attracted considerable attention. The *Minneapolis* is a modern, well-built, protected cruiser of about 7500 tons displacement, embodying all the latest improvements in her machinery. She has, besides her three main engines (each driving a separate screw), between thirty and forty steam auxiliaries, some of which are in operation all the time. During the run above referred to, one of her engineer officers made a series of careful tests on these engines, to determine the steam and coal consumption. It is unnecessary to go into the details of these, but the published results show that about 25 per cent. of the coal consumed was required for the auxiliaries, while their average steam consumption per horsepower per hour was six times that of the main engines.

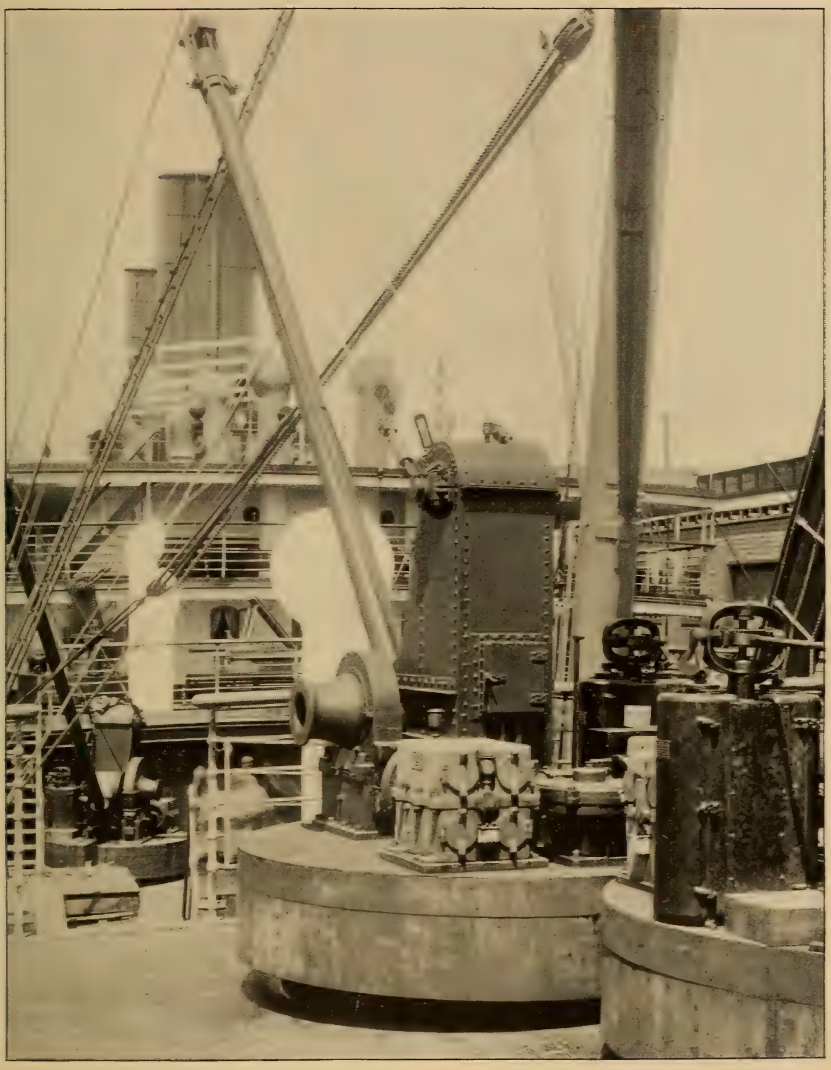
These results are not exceptional; in fact, they are probably better than the average obtained on most warships or merchant vessels. They are, however, very bad from an economical standpoint, and indicate that there is room for radical improvement. It is possible, perhaps, by introducing improved steam engines at a considerable increase in weight and cost, to reduce the coal consumption of the auxiliaries to 20 per cent. of the total, but even this figure is more than twice as great as that which could be attained by enlarging the electric plant of the ship and using electric motors for driving the auxiliaries.

The first cost of such an installation would be greater, but the operating cost would be very much less, and a saving in the daily coal consumption of from 10 to 20 per cent., which would be effected, means that the coal endurance, or "steaming radius," of the ship is increased by just this amount. This is important to merchant vessel and warship alike. Such a system would also do away with all steam and exhaust pipes about the ship, and render the operation of the auxiliaries simpler, less noisy, and much more efficient.



A RUNNING LIGHT TELL-TALE BOARD FOR FOUR LANTERNS WITH SPARE LIGHTS

The only other important consideration affecting the introduction of electric motors aboard ship is the question of their reliability in service. This is



A DECK VIEW OF THE NORTH GERMAN LLOYD STEAMSHIP "BREMEN," SHOWING SOME OF THE ELECTRIC DECK CRANES

an important question on any vessel, and for a warship, it is, in the case of some of the auxiliaries, vital. In action, the ship must steer, the turrets and guns must work, and the ammunition must be supplied regularly, or fighting efficiency is destroyed. Similarly on a merchantman, the hoists and pumps must be ready for use at any time, or the ship's usefulness as a cargo carrier is gone.

Nothing can be simpler in appearance or more likely to run smoothly and without trouble to the engineer having a knowledge of machinery than the modern, compact, well-built electric motor, and it is satisfactory to know that practical experience confirms this appearance and justifies a wider use of motors aboard ship.

A couple of years ago the North German Lloyd Steamship Company equipped two of their vessels, the *Darmstadt* and the *Prinz Heinrich*,

with electrically operated deck winches in place of the familiar, noisy donkey engines. The results were so satisfactory that the later steamer *Bremen* was fitted with sixteen electric deck cranes for handling cargo. The motors and their controllers are mounted directly on the cranes, in an exposed position on the spar deck, and their operation is entirely satisfactory. The motors work noiselessly, and their control is so perfect and yet so simple that any stevedore can handle them. The load on the crane is raised or lowered, or swung to right or left, by a similar movement of the single controlling handle. The capacity of the four larger cranes is 6614 pounds of dead weight, while that of the smaller ones is 3307 pounds.

During the late war between the United States and Spain all the regular United States war vessels were fitted with electric lighting plants, and many of the larger ships were supplied as well with certain electric auxiliaries, such as ventilating fans and ammunition hoists. Two of the *Brooklyn's* turrets were controlled by steam and two by electric motors. Judging from the reports obtainable, all of the electrical apparatus worked admirably, and the performance of the electric turrets on that cruiser was all that could be desired. The reports show that the ease of manipulation and delicacy of control obtained were far superior to anything obtainable with any other system, and these are essential for accurate shooting with large guns.

Some of the new battle-ships now building for several of the world's navies will have their turrets turned and their large guns loaded, handled, and served with ammunition by electricity. It is also probable that in the near future such auxiliaries as the anchor hoist and steering engines, deck winches and boat cranes, ash hoists and pumps of various kinds will be operated electrically on all vessels.

All machinery, to be reliable, requires a certain amount of care and attention, and electrical apparatus is no exception to the general rule; but the nature of its construction is such that this attention can be reduced to a minimum, and its control and operation are so simple that it does not require a skilled mechanic to handle it. The parts subjected to wear and tear of service are simple and easily replaced, and the electric conductors which supply the power are far more flexible, more easily manipulated, and less liable to injury than any other means of power distribution.

THE MINE DEFENCE OF SANTIAGO HARBOUR

By Lieutenant E. E. Capehart, U. S. Navy

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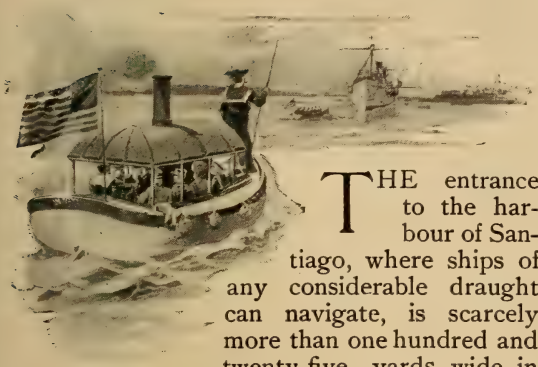


THE entrance to the harbour of Santiago, where ships of any considerable draught can navigate, is scarcely more than one hundred and twenty-five yards wide in its narrowest places, and in order to render it hazardous for American ships to attempt to force a passage during the late war between Spain and the United States, the channel was mined with both electrical and contact mines, the former of the Latimer Clark type, containing two hundred and twenty-six kilos. of gun-cotton, and the latter the Bustamente mine, containing forty-five kilos. of gun-cotton.

The electrical, or observation, mines, were planted in mid-channel, and were controlled, at first, by two stations on the west, or Socapa bank, one on Cay Smith, and one at Estrella Cove on the east bank. The station at Estrella Cove and the inner one on the Socapa bank were in the best possible positions for protection, and could have been operated even should the banks have been swept by the guns of our fleet. In the cove just behind the Morro, the operator could, in almost perfect security, observe his mine field until the ships to be destroyed were almost abeam of him, and could operate his mines long before he could be discovered.

At the Inner Socapa station the same condition of affairs existed, as the station was in behind the hill and close down near the water. Cay Smith and Outer Socapa were not so well protected, but were still commanding positions. The length of channel controlled by these mines reached from the entrance, just off the Morro, up to about midway between Puntilla and Soldados points.

From Cay Smith across the channel, running in about an east-southeasterly direction, a line of nine Bustamente, or contact, mines had been planted also, so that any ship attempting to enter the harbour would, of necessity, be compelled to pass over from eight to ten electrical mines, and then cross a line of contact mines planted so closely together that she must, if of any considerable beam, surely strike one, and possibly two of them in passing.

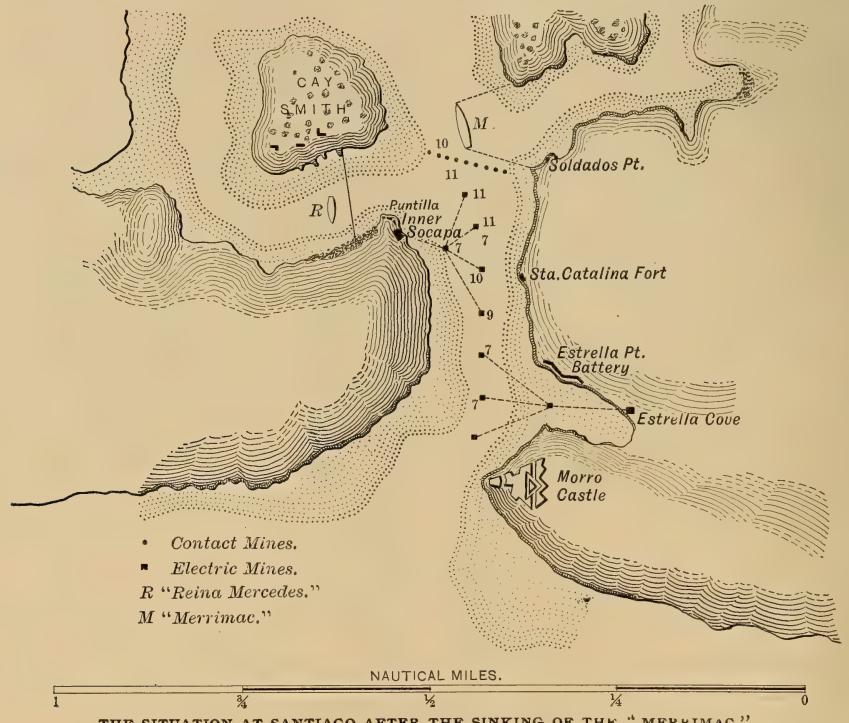
The electrical mines were planted on the bottom in from seven to eleven fathoms of water, and the contact mines were anchored to float at about eleven feet under the surface.

An effort was made to fire the five electrical mines controlled by the station at Estrella Cove when Hobson made his gallant but unsuccessful attempt to block the channel with the *Merrimac*, but only two of the five detonated. Further in another mine was fired from the Inner Socapa station, and Hobson reported that it lifted the *Merrimac* some and probably aided to sink her, as she went down a short distance further in.

After she was sunk the defence of the channel was as follows:—A line of three doubtful electrical mines controlled by the Estrella Cove station, four other electrical mines running from a point just off Santa Catalina Fort up the chan-

nel, and the nine contact mines before mentioned as running from Cay Smith across to the eastern bank, these last running just under the stern of the *Merrimac*. In addition to the mines the channel was blocked by two log booms running from the bow and the stern of the *Merrimac* over to the eastern bank, the logs being secured to each other by five-inch steel hawsers. A similar log boom was also stretched from Puntilla across to Cay Smith. (See Chart.)

The control stations for the electrical mines were small wooden huts covered

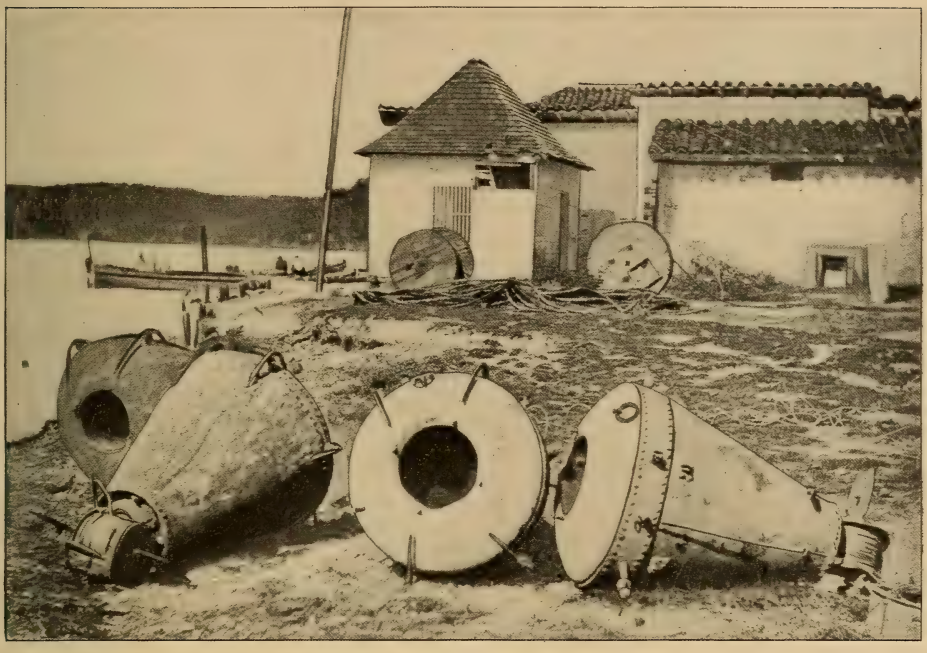


THE SITUATION AT SANTIAGO AFTER THE SINKING OF THE "MERRIMAC"

with branches of trees, and absolutely concealed except for a small slit about four inches deep, and just long enough to take in the two ends of the mine field to be operated. These stations contained the most elaborate electrical appliances for testing the circuits and for firing. A large table with testing battery, Wheatstone bridge, and galvanometer was found in each, together with a firing battery, sighting quadrant, and numerous books giving full descriptions of the ships of our navy, with photographs accompanying. All stations were in telephonic communication with one another. After the surrender it was discovered that, on account of the failure of the three mines controlled by the Estrella Cove station, that station was abandoned. Only parts of the testing and firing mechanism were found there, other parts having been destroyed or carried off. The stations on Cay Smith and Outer Socapa were also abandoned, as the inside station on the Socapa side was considered to be so advantageously located that it, alone, was considered sufficient to control the remaining mines.

SIGHTING QUADRANT

The means of determining the proper moment to fire the electrical mines were a sighting bar in connection with the quadrant of a circle, having on it as many contact points as there were mines in the mine field. The sighting bar was pivoted at the centre of the circle



CONTACT MINES AND CABLE REELS

from which the arc was described, and could be swung around so that its front end could be brought in contact with any one of the contact points on the arc.

The whole arrangement was evidently installed in the control station, and the mines planted on the ranges indicated by the line of sight as given by the bar in its various positions; that is, with its front end on the different contact points of the arc.

The main cable was made up of a number of small well-insulated cables, all bound together and covered with jute braiding for the distance from the control station out to the junction box, and where this cable came in to the control station it was made fast, and the separate parts of it were each led to one of the contact points on the arc of the sighting quadrant. These wires and the contact points were numbered with the same numbers that had been assigned to the mines as they were planted.

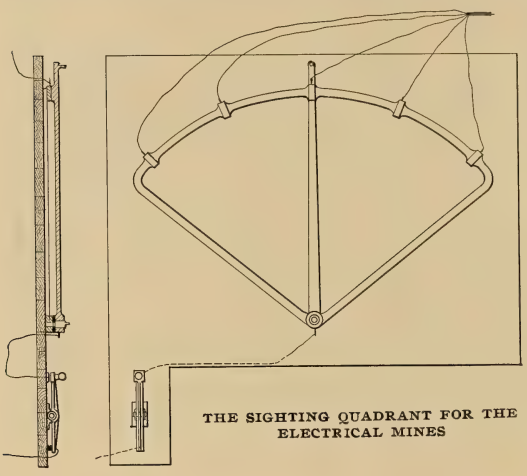
Outside of the control station the cable ran out into the water for about one hundred and fifty yards where it led into a junction box, from which branch leads radiated to each of the mines planted. The mine connection of each of these branches was as follows:—In the top of the mine was a water-tight stuffing-box, through which the leading wire entered and was made fast to one pole of the detonator, the other pole being made fast to the metal of the stuffing-box outside the mine. At the shore end of the cable one pole of the firing battery was placed in contact with the earth, and the other connected to the sighting-bar, the firing-key making a break between the two.

To test any particular mine, place the front end of the sighting bar on the contact point of the arc corresponding to that mine, and, with the testing key and testing battery, in connection with the Wheatstone bridge and galvanometer, the good or bad qualities of the circuit were established. The arrangement was very simple, and, at the same time, very complete.

To fire a mine under a vessel attempting to run the channel, connect

with the firing battery, take the guard off the firing-key, and, when the vessel comes on your line of sight, as indicated by the front and rear sights of the bar, press the key.

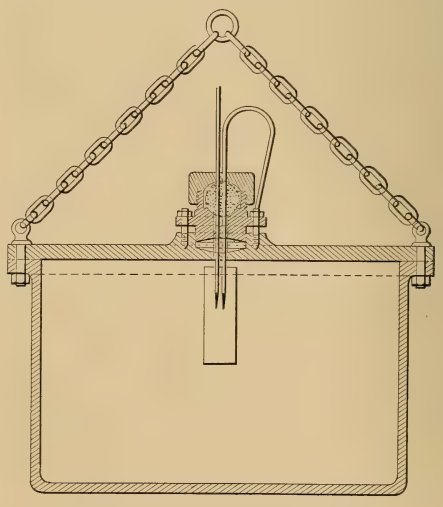
In order to make the entrance of the harbour safe for the passage of our ships



THE SIGHTING QUADRANT FOR THE ELECTRICAL MINES

the commander-in-chief, after the surrender, sent a working party in to destroy the electrical mines and raise the contact mines. Of the four presumably good electrical mines off Inner Socapa, two failed to show continuity of circuit, and, after repeated attempts to detect their faults and to fire them, their positions were located and they were noted "to be raised." The other two were successfully fired, but the column of water thrown up by each was surprisingly small. This may be accounted for, in part, by the great depth in which they were planted.

The two noted "to be raised" were recovered in the following manner, without any accident whatever:—The *Suwanee*, under the command of Lieutenant-Commander Delehanty, was sent in to assist in recovering these mines, as she was fitted with just the sort of anchor gear that was necessary to use in lifting them, and after the chain sling of the mine was once secured, she simply hooked her fish fall in the ring in the end of it and with her steam winch hoisted the mine up clear of the water. All connections at the control station were broken, simply as a matter of ordinary precaution; the main cable was underrun by a dinghy for about one hundred and fifty yards, where a junction box was found. By means of a wrench the nuts holding the top on it were taken off, and the box was found to contain a branch lead from the main for each mine planted, each lead having a tag on it corresponding to its number on the contact point on the sighting quadrant. Knowing the numbers of the two mines fired, it was an easy matter to take each of the other two in turn, and, leaving the junction box in a boat, underrun its cable until the end of a small chain was found stopped to it at intervals. This chain had a ring in its end, and, after casting it adrift from the cable, the boat was hauled over until it led up and down. The *Suwanee* then steamed up and hooked her fish fall in the ring in the end of the chain, hove the mine up above the water, and a steam launch went alongside and received it. A short chain sling led from each corner of the mine to a ring in the centre, and to this ring the hoisting chain made fast. Good



ONE OF THE ELECTRICAL MINES

tackles are absolutely necessary in raising these mines, as they weigh close on to a ton, and, if the bottom is soft, sink into the mud for a considerable distance.

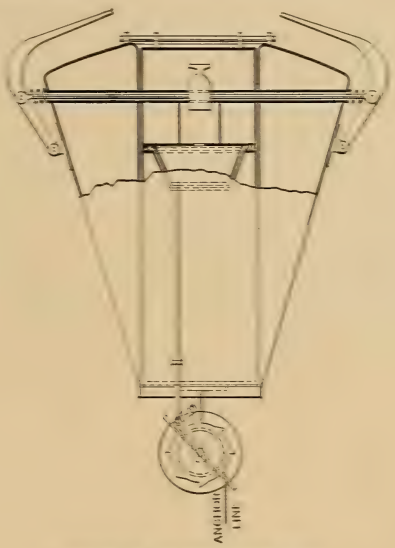
The mines recovered were of the following general description:—The case was of cast iron, about three-quarters of an inch thick, the top and body being cast separately, and after the charge of gun-cotton had been placed inside, these were securely bolted together, with a rubber washer between them. The whole thing was in the form of an iron box about thirty-six inches on a side, and about twenty inches deep, and, as stated before, the leading wire entered through a central water-tight stuffing-box. The detonating agents were two fulminate of mercury detonators, each containing about seventy grains, as well as could be judged, connected in parallel, and embedded in the heart of the dry gun-cotton primer.

To prevent injury to the connections, from pulls or sudden jerks on the leading wire, a cuckold's neck was turned in it and made fast to a ring in one of the corners of the mine. As soon as the mine was in the launch the stuffing-box was taken off to permit of an examination being made, and this should always be done if recovering a mine that has failed to fire. If the detonators have fired, well and good; if not, then remove them from the mine at once as a matter of precaution. The remaining mine off Inner Socapa and those off the Estrella station were recovered in the same general way by the *Suwanee*.

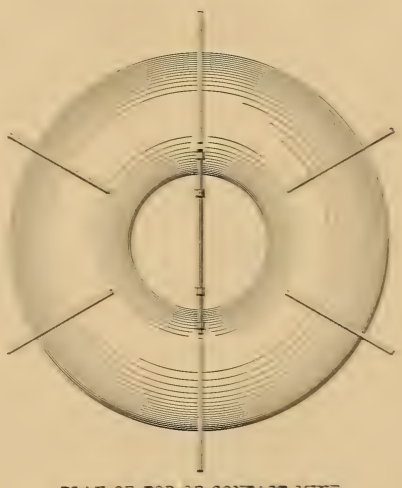
CONTACT MINES

The line of contact mines, running from Cay Smith across to the eastern bank, passed just under the stern of the *Merrimac* and completely blocked the channel; but on the afternoon of July 2, 1898, four of these mines were taken up between Cay Smith and the *Merrimac*, and, on the morning of July 3, the connections at Inner Socapa were temporarily broken so that the Spanish fleet passed out in perfect safety. After they had passed the mine fields the connections were immediately made again, and the four contact mines planted in their original places.

The operation of recovering these contact mines will probably be better understood after a brief explanation of the method of planting them and a description of the different parts have been given. The description, as here given, is of the mine as it was found at Santiago, and may not be exactly technically correct according to the ideas of the inventor, but is correct regarding



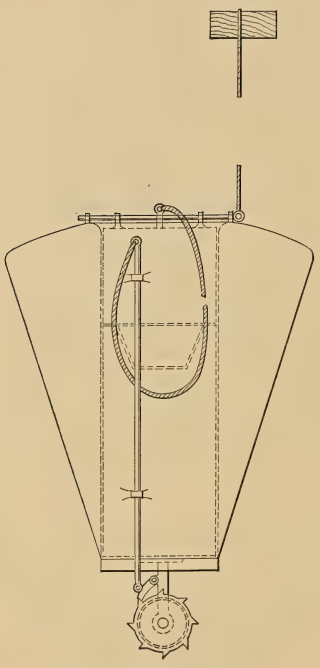
ONE OF THE CONTACT MINES



PLAN OF TOP OF CONTACT MINE

those recovered. The mine is in the shape of a conical buoy thirty-two inches in diameter at the top, and twelve and one-half at the bottom, and stands thirty-six inches high. It has a central axial hole in it, eleven and three-quarters inches in diameter, for the entrance of a cylinder containing the charge of wet gun-cotton. The bottom of this hole is closed by an iron plate, and on the outside of this plate is secured the frame of a reel which carries about twenty fathoms of wire rope for anchoring the mine. On the barrel of the reel is a toothed wheel, against which a pawl is held by a spring, preventing rotation until the pawl is raised.

On each end of the barrel, outside the frame, is a two-bladed fan, the area of



ATTACHMENTS FOR RAISING A MINE

ach blade being about sixty square nches. When the pawl is lifted, by a rod running up alongside the mine, it releases the reel and allows the wire to unwind, and by letting go this rod the spring holds the pawl hard against the toothed wheel and stops the revolution of the reel. The fans are to prevent a too rapid revolution of the reel and a consequent snarling of the anchor wire.

The cylinder which fits in the central hole in the mine contains forty-five kilos. of gun-cotton, and is secured to the bottom plate by four bolts and nuts, but does not reach to the top of the mine by about eight inches.

In the upper end of the cylinder is a conical hole for the reception of a vessel containing the dry primer of gun-cotton. This vessel, containing the dry primer, is secured against a rubber washer on the bottom of a small hollow cylindrical buoy, which fits in the upper end of the same axial hole as the large cylinder containing the wet charge.

Inside of the small hollow cylinder are six plungers, spaced at equal distances around the circumference, and converging to the centre, where their inner ends rest on a glass tube filled with sulphuric acid, their outer ends being in contact with plungers operated by contact arms on the outside of the mine. The hole in the small buoy where the outer ends of the plungers make contact with those operated by the contact arms is covered with thin sheet lead to make the buoy water-tight, the blow from the contact arm being sufficient to rupture this lead when the mine is struck by a passing vessel.

Around the tube of sulphuric acid is a composition of chlorate of potash and sugar, and a central hole gives communication between this composition and the dry gun-cotton in the conical vessel attached. To the eye, the only substances that could be absolutely determined were the chlorate of potash and the sugar; but this alone will not make, with sulphuric acid, a detonator. Therefore, there must have been some fulminate in combination with these two substances, or in the heart of the dry primer of gun-cotton, to produce a detonating effect. I quote from an opinion of the chemist at the United States Torpedo Station, Professor H. F. Brown:—

"The reaction of sulphuric acid, potassium chlorate and sugar will evolve a large amount of heat and will proba-

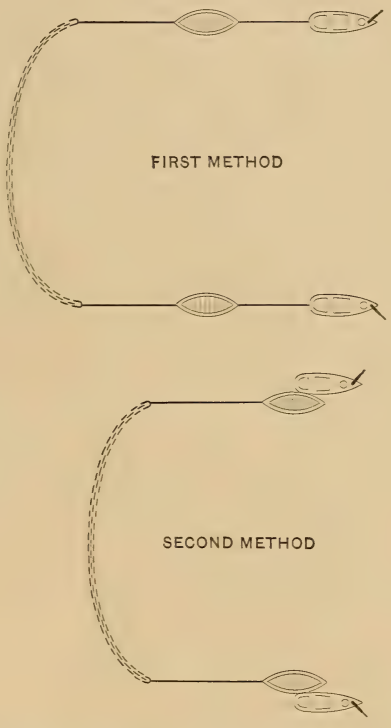
bly result in an explosion. The explosion will ignite dry gun-cotton, which, consequently, will produce an explosive effect. It is my opinion that this explosion will not be a true detonation unless there intervenes some fulminate of mercury, or other substance, whose ignition, like that of the fulminate, amounts practically to a detonation. I should not expect the explosion of a mass of wet gun-cotton which might be adjacent to the dry primer (of gun-cotton)."

This opinion is fully substantiated by other authorities, and, therefore, although no fulminate appeared to the eye of the observer, it must have been there, or the mine would have been valueless. The detonating agent is, therefore, the material in the buoy and the dry gun cotton primer.

In planting the mines the buoy and dry primer attached are placed in position in the upper end, as a last preparation, and a small rod is run across the top of the mine through lugs, to hold it in place. To one end of this rod a line is made fast, and to the end of the line a small wooden buoy is secured, intended to act as a signal buoy, the length of the line being so judged that the buoy will float a short distance under the water when the mine is planted. The buoy carrying the dry primer has a ring in its top to which a line, from the upper end of the rod operating the pawl on the reel for the anchor wire, is made fast.

The depth of water is known, as is also the depth below the surface at which it is intended the mine shall float. Having the mine slung, pull up on the rod operating the pawl on the reel and allow the wire to run out to the depth of water, minus the depth below the surface at which the mine is to float; let go the rod and lower away gently on all. The mine is pulled down under the water and floats at the depth determined upon, while the small wooden buoy, acting as a locating buoy, floats about one foot under the surface.

The location of the line of contact mines was known, approximately, before the surrender, and this knowledge was verified by the commanding officer of the Spanish gunboat *Alvarado*, captured in the harbour. A small boat was used in raising the mines, and the work was carried on in the early morning on account of the light and smoothness of the water, which became rough later on in the forenoon and made it difficult to locate the signal buoys. Once on the range the boat was pulled slowly, with a number of watchers on each side. As soon as one of the small wooden buoys was sighted it was secured, and by pulling on the line steadily the pin running across the top of the mine, holding the cylindrical buoy, with dry primer attached, came out, allowing the latter to rise to the surface quickly. Attached to the ring in the top of the cylindrical buoy is a line which, as already stated, has its lower end made fast to the rod operating the pawl on the reel for the anchor wire. Pull up on this line, lift the pawl, and



METHOD OF DRAGGING FOR SUBMARINE MINES

allow the wire to unreel until the mine comes to the surface.

Lift the cylindrical buoy, with dry primer attached, in the boat, and you have nothing to deal with in the mine but a charge of forty-five kilos. of wet gun-cotton. By pulling up on the rod operating the pawl of the reel, and reaching down with a boat-hook, the bight of the anchor wire was secured and the anchor weighed. A line was then made fast to the mine and it was towed ashore and hauled up on the beach. The work of recovering eight of these mines required less than a day. This method of recovering contact mines presumes, in the beginning, that their location is fairly well known, as, otherwise, the plan of sweeping for them with two boats must be carried out, as was done by the *Marblehead* and *Dolphin* at Guantanamo.

The work of sweeping for the mines at Guantanamo was done at the time when those engaged in it were likely to be subjected to the fire of Spanish riflemen in pits on the left bank of the channel leading up to Caimanera. These pits were covered by the guns of the two ships whose boats were engaged, whilst the pulling boats, in tow of the steam launches, also contained riflemen. The general plan was to sweep with the chain, and line between the boats as indicated in the sketch on this page, and when a mine was secured, place wedges between the body of the mine and the contact arms, as a precautionary measure, until the dry primer could be taken out.

Before leaving the subject of contact mines I wish to say that I discovered an appendage to some of those recovered which I was at loss to understand. This was a small cylindrical buoy about five inches high, and about eighteen inches in diameter. This was attached by a line to the rod operating the pawl of the reel for the anchor wire. It apparently had been intended to act as a buoy in the original design; but, as found at Santiago, there were holes punched in its sides, as though by a nail, and the result was that, instead of acting as a buoy, it had an appreciable weight to it and pulled down on the rod to which it was attached, thus assisting the spring to hold the pawl on the toothed wheel. On some of the mines this was missing, and its office on those where it was found seemed to be of very little importance.

During the latter part of June, 1898, a plan of countermining the channel leading into Santiago was developed and approved by the commander-in-chief, the officers who had volunteered to carry out the scheme reporting everything ready on July 1.

The destruction of the fleet, the surrender of the Spanish army, and other incidents, made it unnecessary to carry out the plan as developed; but it is simply noted here that the plan was after the accepted ideas of all nations, —that is, to explode, simultaneously, a number of heavy mines, containing about five hundred pounds of gun-cotton in the mine field. These mines were to have been dropped in succession from a boat, towed by a fast launch or steamer, and the whole exploded as the last mine reached the bottom. The explosion of a countermine of five hundred pounds of gun-cotton will destroy all mines within a radius of from two to three hundred feet, and the practical application of the proposed plan had every chance of success.

The mine fields were well protected by many rapid-fire and machine guns secreted on the Socapa side of the entrance, the guns and carriages being painted the same colour as the earth, and almost entirely covered with brush. Between Puntilla and Cay Smith the *Reina Mercedes* lay in the cove, protecting the line of contact mines, whilst Punta Gorda battery could fire straight down the harbour. Added to this, the brush on each side of the entrance was thick with concealed riflemen.

Nature had done everything to assist in the protection of the channel, the electrical mines were of the most approved type, and the contact mines, if properly attended to, were dangerous to an enemy. But the very best of tools, if placed in the hands of inexperi-

enced or indifferent workmen, will seldom give good results.

The mines in the entrance were said to have been planted by the officers of Admiral Cereva's fleet, and there were many evidences of the hurry with which they were put down. Lieutenant-Commander Delehanty, who commanded the *Suwanee*, and who lifted the observation mines with his ship, says:—

" None of the mines were recovered intact. The connections were, as a rule, broken, the dry primers drowned out, or the mines partially exploded."

In many places the coverings of the branch cables were chafed off, and some of the strands of the wire bare; the result, no doubt, of paying the cable over the gunwale of the boat used in planting the mines.

The maxim, " that insulation is for the purpose of making electricity go where we want it to go," had evidently never occurred to the officers engaged.

In one electrical mine recovered, there was evidence of a partial explosion, which did not show at the surface of the water. The bottom of the mine was partially blown away, leaving about one-half of it intact, and inside the mine was a large quantity of wet gun-cotton, which rolled out of the hole in the bottom as the mine was lifted and lowered into the launch alongside of the *Suwanee*.

In firing exercise spar torpedoes at the torpedo station, the writer has seen it frequently happen that a leak in the top of the case would admit enough water to prevent a detonation, but the case would be ruptured and the torpedo, on recovery, would show that the detonator had gone off, but that the dry primer had become damp or wet. A careful examination of the mines recovered seems to indicate that one of the small, and almost insignificant points connected with the preparation of mines had been entirely ignored. I refer to the method of securing the stuffing-box to the top of the mine. The fact that so many mines had the dry primers drowned out, together with appearance of the stuffing-box, proved that, instead of screwing down gradually on the nuts, securing the stuffing-box to the mine, so that the flange would take equally all around, one side was screwed down tight, and then an attempt was made to screw down the other side. Experience proves that this is not always possible, and I believe that this accounts in a great measure for the failure of most of the mines.

Another point was that the mines seemed to be placed too close to each other. Taking the length of channel to be guarded, and considering the fact that five hundred-pound mines may be destroyed if within three hundred feet of each other, it appears that these were too close, and the detonation of any one of them would, if it did not detonate the others next to it, at least, destroy their electrical connections and render them absolutely useless. This did happen at Estrella, and I believe also at Inner Socapa. The mines that were fired at the *Merrimac* utterly destroyed the connections of the three that were left at Estrella.

To get the full effect of a mine a ship must naturally be over it, but this can seldom be brought about unless two control stations are occupied. After the *Merrimac* sank, all but one of the stations at Santiago were abandoned, and therefore it would have been a stroke of extremely good fortune had a mine been detonated at the exact moment when a ship was over it. Experiments have, however, been made to determine the horizontal distance at which an armoured vessel would be vitally injured by different charges of gun-cotton in mines, the following being the results:—

Mine.	Submergence.	Dist. horizontally.
150 lbs.	10 to 15 feet.	4 feet.
250 lbs.	30 feet.	10 feet.
500 lbs.	60 feet.	15 feet.

This last corresponds nearly with the conditions existing at Santiago, but with the faults in the circuits, and the other attending difficulties, it is scarcely likely that these figures would have been reached.

CONCLUSION

Contact mines of the typeen countered at Santiago and Caimanera are lia-

ble, from the growth of barnacles, to become very much impaired as regards the operation of their different parts, especially the contact arms. This growth forms so rapidly in the warm water of the tropics that in a very short space of time it is sufficient to prevent the arms from driving the plungers in far enough to break the vial containing the sulphuric acid. They, therefore, require constant attention, and from observation it seems that, to make them effective, they should be raised and cleaned about once in three weeks. The examples of the *Texas* and *Marblehead* picking up on their screws mines of this description, are sufficient to illustrate the harmless condition to which they may revert, no matter how good they may be when planted.

Had due care been exercised in planting the electrical mines, and a fair amount of attention paid to the contact mines in Santiago harbour, no ship could have passed the two fields. But the well-known character of the people who planted and attempted to operate them accounts, in a great measure, for the condition in which they were found.

The moral effect of a mined harbour is tremendous, and the question of risking valuable ships is of vital importance. What would have happened to a ship attempting to run the mine field is problematical, but the chances were that she would have been sunk, for, notwithstanding the number of bad mines encountered, enough good ones were left to destroy her. The electrical mine was perfect in type and design, and had it been properly planted and cared for, the protection given by it to the entrance would have been absolute.

The lesson to be learned is evident, —mines cannot be planted hurriedly and carelessly, allowed to remain without attention, and then be expected to give theoretical results.

Officers of Admiral Cervera's fleet stood watch in the control stations at Santiago, and must, naturally, have been alert and attentive to their duties, so that in considering the matter from all sides the facts which come home to us are these:—The theoretical knowledge of those who selected the firing stations, planted the mines, and weighed the question of properly defending the channel was fairly perfect, but in the vital point of a practical knowledge of how to prepare and plant these mines they were deficient.

It does not require much of an argument to convince us all that practical education in this particular branch of our profession is what the service needs. The details, at times so seemingly insignificant and unimportant, are just the trifles which make success or dismal failure. In a mine defence one cannot admit, for an instant, that there is a chance of failure, for it must be so perfectly installed that it may be counted upon with absolute confidence. This is feasible and possible, and without a knowledge of the important details no assured success can be expected in either mine defence or countermining.

DEPRECIATION

By Joseph Nasmith

THERE is no subject on which there is such divergence of opinion, as that of depreciation. Volumes have been written at one time or another, and discussions without end have been commenced and finished, and yet it is barely possible to find two men who agree upon the subject. As set forth by the writer in a paper read recently before the New England Cotton Manufacturers Association, depreciation has been looked upon as a subject strictly within the province of accountants and as having very little bearing upon the actual work of a mill or workshop. It has, in consequence, fallen into the category of academic discussion, which centres mainly around the point as to how it should be computed. As a matter of fact, depreciation is of more importance than this, and deserves special consideration at the hands of those practically engaged in manufacture.

In all modern enterprises the element of capital enters into the problem to be solved. When the earth was young, tillage of the soil was the only method of subsistence, and primeval man, like the savage of to-day, laboured only in order to obtain sufficient food for his sustenance, and clothing to protect him from the elements. The exercise of this labour yielded no capital until more was produced than was wanted for individual needs, and accumulation began. As society developed, the accumulated stores of various natural products afforded a means of barter by which one individual could obtain from another something he desired to possess in exchange for some object required by his fellow. Individual barter gave way to tribal trade, tribal to national, and so the great volume of international commerce developed. In time, standards of one kind or another were set up which speedily assumed monetary form, and the accumulations of past labour and trade were gathered together in that form, and began to be specifically called capital.

Capital, viewed merely as accumulated wealth, is of no value unless it is employed in some way to aid in the production of articles useful or necessary to mankind, and accordingly we find that it is customary to lend this accumulated wealth for various purposes in the hope that its employment will enable labour so to handle natural products that they may be disposed of at a rate which is capable of providing for the wants of the labourer, and of yielding a surplus for the person providing the capital. These are truisms which only lead up to a consideration of the various employments of capital upon which the question of depreciation so largely depends.

There is no question that the simplest outlay in the form of capital is that which is expended in tilling the ground. At first this was merely the application of labour, as it is in some countries to-day, where the labour is that of the owner only, and there cannot be said to be any capital employed. When, however, the owner finds that he has enough accumulated profit, either in kind or money, to enable him to find employment for others beside himself, paying them a portion of the product and reserving the rest to himself, then capital enters into consideration. Gradually he acquires a stock of implements of more or less value by means of which

his operations are aided, and these form his plant. If, instead of tillage, he takes to mining or quarrying, he must still use plant of some kind in order to conduct his operations, but in either of the cases stated, when the operations are suspended, no amount of money previously expended leaves him any asset which is of value other than that of the plant used. The earth, whether tilled, quarried, or mined, remains of equal value before and after the operation, and any loss which occurs is only that which is represented by the diminished value of the plant used during work. In other words, there is no capital value in the business except when it is being conducted.

In the case of a manufacturing concern it is obvious that the land plays a comparatively small part, as the proportion which its cost forms of the total expenditure is small. Not only is the resultant product not obtained by the manipulation of the land, but by that of the plant and machinery placed upon it. It is, therefore, necessary to deal with a new set of conditions to those existing in the case of agriculture. Instead of expending labour upon the one natural material which is common, it is necessary to use other things which can be so operated as to produce some article useful to us and capable of sale. Thus, the buildings which contain the machinery, the machinery itself, and the accessories needed form the greater part of the value, and it is chiefly in respect of these that it is necessary to take into consideration the question of providing a sum to enable them to be replaced when they are no longer able to produce the article required.

The amount thus indicated has come to be known as depreciation, and it is worth considering for a short time what this should cover. What, then, is depreciation? Primarily it is, of course, that allowance which should be made to cover the inevitable deterioration in any machine or article used, so that at the expiration of the period when it is no longer capable of economical employment a sufficient sum will be accumulated to replace it. In short, it is a payment out of revenue of a sum equal to the amount of capital absorbed in earning the revenue.

In a sense this is a reserve fund, and should be treated exactly in the same way as the latter,—that is, the amount set aside should be rigidly reserved, in order that it will be available for the purchase of the machines or articles which need replacement at the period when that is needed. It is a common practice to deal with the allowance made for depreciation merely as a matter of account; but it is only a sham unless the actual sum so accumulated is, at the termination of the predetermined time, available either in cash or kind,—preferably the former. A reserve fund is thus created, which differs from that ordinarily known by that name only because it is ear-marked and set aside for a specific purpose, the ordinary fund being available for any of the purposes of the business. The charge for depreciation is one which constitutes a special expenditure for a specific purpose, and must be so regarded. It diminishes the profit made to the extent of the charge, and would, if not taken into account, be reckoned as part of it. It is, therefore, in its essence, reserved profit, and as such should be tangibly represented either in cash or some other form equivalent thereto.

There are, however, other considerations of importance in the case which are more complex. Primarily, it was said, depreciation is an allowance for the natural deterioration of the machine or utensil, which means capital expended, and in this form should always be made. As to the amount of the allowance, this depends on many conditions which will be fully considered a little later; but there is another aspect which demands special thought.

While the examples given later are confined to textile factories, it may be said that the same principles underlie all cases, and only need special application. In the case of a machine it is requisite to consider that not only does it wear out, but that owing to the efforts of inventors and constructors it may become, if not obsolete, not equal to

machines of a later date. It is quite clear that in some few cases where a startling invention occurs, the whole value of any machine may be destroyed at one stroke; but this is an extremely rare,—nay, almost unknown,—occurrence. As a rule, the work of evolution proceeds in stages, sometimes quickly, sometimes more slowly; so that the unfortunate manufacturer does not suddenly find his machinery and plant rendered obsolete and of no value. But it is obvious that, however, slow, this factor is one to be reckoned with, and does undoubtedly diminish the value year by year.

As an example of what is endeavoured to be enforced, take the spinning frame. The old throstle or flyer spinning machine was,—although in some respects the best ever used,—incapable of producing more than a given quantity of yarn per hour. In consequence, the efforts of inventors were turned to other modes of continuous spinning, and the ring frame was evolved. At first, owing to imperfections in the method of manufacture, the gain was not large, and was to some extent diminished by the comparative great power needed to drive the machine, and the frequent breakages. The great conception of Sawyer, that it was possible to obtain a point of support high up the bobbin, speedily led to improvements, and the combination of this principle with that of a self-contained spindle, which was the work of Rabbeth, carried the process further.

But evolution was not yet at an end, and the application of the humming-top principle to the spindle gave a further impetus to the productive capacity of the machine. Moreover, while the inventor was busy, the constructor was not idle. Grateful as we ought to be to those whose conceptions have led to the evolution of the best forms of spindle, it is certain that at least as much is due to those able constructors whose constant vigilance and effort have so improved them as to add considerably to their value and efficiency.

The instance given shows that changes take place gradually; but it is quite clear that a spinner whose mill was equipped with frames having flyers would find its value much diminished on the introduction of ring spinning, and similarly would suffer proportionate loss if, having put in machines fitted with the common ring spindle, the newer type became an operative success. Further, the diminution in value is affected not only by the increase in the working velocity of the spindle, but also by the greater efficiency, owing to better construction, which leads to a greater continuity of work. An increased production, at all approaching the amount arising from the introduction of ring spinning, renders it imperative, in the face of competition, that the new instrument shall be adopted, and thus, unless it can be applied to existing machines, —utilising some of the parts,—destroys the entire value of the latter, except that of the material.

Let it be assumed that a still further step be taken! It is common knowledge that many attempts have been made to spin yarn on the bare spindle of a ring frame. Hitherto success has not followed any of these efforts; but let it be assumed that some one solves the problem. Part of the cost of a ring mill consists of the bobbins which are perforce used. This at least would be rendered unnecessary, and the bobbins would cease to have any value in this connection. Further, let it be assumed that in order to produce cops on a continuous spinning frame a radical change is made in the character of the spindle used so as to obviate the necessity for a ring and traveller; it is clear that the value of existing machines would at once suffer diminution. Much more striking would be the effect if some change in design resulted in the capacity to spin much finer counts than is possible on a ring frame, while retaining the continuous principle. This would be little short of a revolution, and would lead to an enormous diminution in the value of mule plants.

There can be no doubt, therefore, that in considering the question of depreciation, it is essential to take into account fully not merely the deteriora-

tion arising from wear and tear, but also the decrease of value consequent upon the production of new mechanical contrivances of greater power and capacity. These considerations apply in a lesser degree to buildings, but they do apply, because a given class of machinery is best arranged in a building of specific dimensions which may not be the best under other conditions. For instance. it is customary to provide so many cards and speed spindles for a given number of spinning spindles. It needs no demonstration that an increase in the productive capacity of any of these will affect the required number of the others, and that where a building has been designed to hold conveniently and economically the specified machinery, it will not be so well adapted under the changed conditions. It is quite true that this consideration has not so much force in the case of buildings as it has in that of machinery, but it is not entirely to be lost sight of, as will be readily admitted if a mental comparison be made between the mill building of twenty years ago and that of to-day.

Having thus laid down the principles of the subject, it will be easy to deal with their application, although there are many considerations of importance to deal with. In the first place, it is evident that the amount allowed for depreciation must always partake of the nature of an estimate. It is quite true that, in some cases, past experience will enable an approximately true estimate to be made of the loss from wear and tear, but even this is largely affected by changes in form or construction leading to superior velocities. It is, however, equally certain that not even an approximately true estimate can be formed of the diminished value likely to arise from new inventions or improvements in construction, because that would necessarily be prophetic and not based upon any definite data. There is no doubt that an older and inferior machine at a certain value may be considered equal in productive capacity to a newer and superior one at full value, but it will be found that a full review of all the circumstances will lead to the conclusion that the value must be very low.

Having thus formulated the principle underlying the subject, it is necessary to deal now with the correct mode of estimating the amount which is required to provide for the loss of capital which follows upon the use of a machine. It is customary to fix a definite percentage of the value of the machine or building and deduct it from the value year by year, the percentage being fixed by assuming a definite life for the machine. Thus it may be assumed that a speed frame has a life of 20 years, so that a deduction of 5 per cent. yearly from the original value will at the end of that term provide a fund to purchase a new machine of equal value. Such a procedure is simple, and hardly requires explanation; but while safe so far as wear is concerned, it does not meet all the conditions. Further, it may well be that although a life of twenty years may be fairly presumed for a speed frame, it is not equally safe to fix the same period in the case of a loom. In other words, while the fixing of a single rate to cover the depreciation of all machines may be convenient, it is far from being accurate, because some wear faster or tend to become less efficient more quickly than others.

For instance, compare the action of a spinning frame with that of a loom. In the one the motion, although rapid, is continuous, and comparatively free from shocks; in the other, during the whole period of work, the motion is intermittent and violent. It is obvious that in the one case the conditions as to wear are favourable, while in the other they are unfavourable. Thus, the character of the machine, the work it has to do, and the care bestowed on it have a great influence on the question of depreciation, and render it necessary to consider these factors in fixing a charge. It is also desirable that the position in which a machine is placed should be considered, as in some cases there are local circumstances, such as damp or dust, directly tending to a depreciation of the machine. It is, therefore, essential not only to look at the

matter in bulk, but also to consider the machines in detail, in order to ascertain whether one wears out more quickly than another, so that the proper allowance may be made in each case. In a spinning mill there is not much difference in the rate of wear of the various machines, because they are all run at regular speeds and without shock; but it is clear that even in this case a drawing frame is not liable to deteriorate so rapidly as a mule or a picker.

While the working of a machine tends towards a diminution of its life, the repairs upon it from time to time tend to an increase of the latter. It is, thus, necessary to make some provision in the estimation of yearly value for the effect of the expenditure on repairs. It should be borne in mind that the effect on the value, measured by an increased capacity of the machine for work, does not always coincide with the money cost of repairs. More money may be spent on the latter than represents the value added to the machine, for while there is, beyond doubt, an increase in value, it may not be equal to the expenditure. The general effect of repairs is, however, to extend the life of the machine, and looked at merely from the stand-point of wear and tear, they should be charged as an offset to the depreciation in the year when they occur.

On the other hand, extensive repairs when the machine is old do not affect the question of its comparatively diminished value in view of improvements made in the design and construcion of similar machines during its life. This is a factor to which it is impossible to give any definite yearly value, but it is one to be reckoned with, nevertheless. It can only be taken into account properly by adding periodically a special charge, but it is met to some extent by the decreased value of the machine arising from the operation of the regular charge.

It is urged, therefore, that there are many considerations to be taken into account in reckoning depreciation. These are:—

1. The loss of capital by the natural wear and tear occasioned by work and by neglect or carelessness.

2. The addition to the value at any given period which results from effective repair.

3. The character of the work to be performed, and its effect upon the construction, operation, and amount of wear of the machine.

4. The loss of capital caused by a decrease in the relative value owing to the introduction of superior instruments capable of more economical results.

In fixing the amount set aside for depreciation, we are at once met with a bone of contention. Shall the fixed amount be deducted yearly from the original or depreciated value? In other words, shall the life of the machine be taken as the period during which its cost shall be provided for, or shall there be at the expiration of that time a residual value which is equivalent to an extended life? It is quite certain that every machine which is replaced has some residual value. The material of which it is composed is worth something, and to that extent the absolute wiping out of its value in a given period is unjust. Generally speaking, however, the amount is not large and may, in any case, be allowed for in making the calculation of the yearly allowance.

It may be fairly argued that the plan of deducting equal yearly instalments tells very heavily when the machine is worn and is less effective, while the deduction of a diminishing yearly sum depreciates sufficiently at the beginning, when the machine is at its best, and less after its working value is decreased. While this is true, it is purely a matter of account; and it is permissible to adopt the plan named only when the residual value at the expiration of the fixed period is only equal to that of the material.

For instance, if a machine be valued at £100, and is depreciated at 5 per cent. per annum on that amount, then, at the end of 20 years the cost is wiped out. If now the percentage be deducted only from the diminished value annually, then at the end of the time named there will be still 36 per cent. of the

original value remaining. Now, it is obvious that no machine is worth at the expiration of such a term 36 per cent. of its original value,—at any rate, no textile machine is,—so that the method of computation named is of no value. If, therefore, the allowance is to be deducted from the depreciated amount yearly, then the rate must be higher at the beginning of the term than at any later period, and must, indeed, be on a diminishing scale throughout the whole period, in order to reduce the value to its proper level. On the whole, it is better and simpler, considering the purpose of depreciation, to deduct annually a fixed sum from the original cost, so that there may be some period when the account will close.

There is one other matter which deserves special consideration, namely, the question of how to charge loose tools or accessories. In connection with all textile machines there are always a number of accessories, such as bobbins, skewers, skips, shuttles, etc., which, while not being part of the machine, are yet essential to its working. It is idle to charge these to capital as plant, and wherever this is done the account will not be kept properly. They wear out much more quickly, and require renewing more frequently, than the machines in connection with which they are to be employed. So that, if they are treated as plant, they require a much greater amount written off annually. The proper way to treat them is to catalogue them at every stocktaking, charging against revenue all additions made during any period, and valuing them as a special item for use in a going concern. This system has the advantages that it gives a check on the inevitable leakage which always takes place in a manufacturing concern, and provides for the renewal of all accessories out of the yearly income.

The writer is aware that there is not much new in what he has said, but the whole subject is one which is capable of many points of view. Summing up the special desiderata in the treatment of this charge, the writer thinks that it is desirable to charge a definite percentage on the value of a machine every year for a term which may be fixed as the life of the machine. The length of the term should be controlled by a special consideration of the probable life of each machine, but where a set of machines are employed, the life of which is approximately equal, then the deduction can be made from all at the same rate.

As depreciation forms a special reserve fund for a specific purpose, it should be adequate to provide for it, as it is better to err on the side of excess. It is becoming the practice in the English cotton trade to charge a definite yearly sum to depreciation, instead of a percentage, care being taken to make it adequate.

Loose plant and accessories should be charged against revenue, and not counted as plant, and care should be taken to keep them up to full value year by year.

THE STORY OF SMOKELESS POWDER

By Hudson Maxim

ALTHOUGH the production of a satisfactory smokeless powder, and one well adapted to the needs of present firearms, is a very recent event, the first discovery in this line dates back to early in the present century, when Braconnot, of Nancy, in 1832, found that starch and similar bodies were rendered highly combustible by treatment with nitric acid. Pelouze, six years later, conducted further experiments with nitric acid on cotton paper and other vegetable substances. Dumas, a little later, produced, among other substances, what he termed a nitramide, prepared by treating paper or cardboard with concentrated nitric acid. These early discoveries resulted in nothing of practical value, due to the lack of sufficient knowledge of the nature of the substances produced and the necessary means for giving them stability.

The most important step in laying the foundation for the production of high explosives and of smokeless powders was made by Schönbein, who discovered, in 1846, a method of making true guncotton. He was the first to add concentrated sulphuric acid to the nitric acid bath for the purpose of more highly concentrating it, and at the same time for absorbing the water set free by the reaction of nitration.

In 1846 Böttger, of Frankfort-on-the-Main, made the same discovery independently of Schönbein, the latter having kept his method a strict secret until he learned of the work done by Böttger. The two inventors then joined hands in the exploitation of their invention, and in recommending its use as gunpowder and as a blasting agent.

In 1847 Sobrero, reasoning from analogy, concluded that as guncotton, starch, etc., could be nitrated after the method of Schönbein and Böttger, pure glycerine ought to be similarly changed when so treated. This invention Sobrero verified by actual experiment in 1847 in the laboratory of Pelouze. In the same year collodion cotton and its solution in ether and alcohol was discovered by Dr. Maynard, of Boston, Mass., U. S. A., and introduced into surgery by him.

Experiments have shown that a very large number of varieties of guncotton may be produced, depending upon the amount of concentration of the acid mixture, the proportions of the acid employed, the temperature of the acids and the period of immersion of the cotton. One company, manufacturing celluloid, claims to have produced upwards of six hundred different varieties of nitro-cellulose. The most important and useful are five in number:—

First, celluloid pyroxylin, of a very low degree of nitration, soluble in camphor, but insoluble in nitro-glycerine, and unsuited for making collodion or varnish.

Second, collodion cotton, soluble in ether and alcohol, and insoluble in nitro-glycerine.

Third, varnish pyroxylin, very soluble in wood alcohol and other menstra, to which it imparts much more body than any of the other varieties of nitro-cellulose.

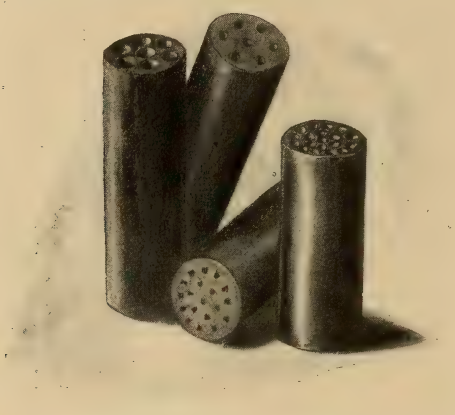
Fourth, gelatine-pyroxylin, soluble in nitro-glycerine, with which it forms a tough, elastic jelly. Gelatine-pyroxylin

is not suitable for collodion or varnish, for the reason that it thickens the menstra without imparting sufficient body, and the solution does not flow or spread well.

Fifth, tri-nitro-cellulose, or insoluble pyroxylin, which is neither soluble in nitro-glycerine, wood alcohol, nor a mixture of ether and alcohol, but is readily soluble in concentrated acetone and the acetates of methyl, ethyl, and amyl.

All of the above grades of pyroxylin, except tri-nitro-cellulose, are, in common parlance, termed soluble.

After Schönbein, Captain Von Lenk was the most important experimenter in the production of guncotton; he overcame many of the difficulties of its manufacture, and did much in the direc-



UNBURNED AND PARTIALLY BURNED GRAINS OF MAXIM-SCHUEPPHAUS SMOKELESS CANNON POWDER

tion of purifying both the raw material and product. In 1849 to 1852 the work of Schönbein and Böttger had been much improved by Von Lenk, and the Austrian Government contracted with them for the use of their invention. In 1853 a guncotton factory was erected in Austria, under the charge of Von Lenk.

The latter soon recognised the necessity of taking steps to slow the action of combustion of the nitrated cotton, in order to adapt it to use as a gunpowder. To this end he plaited the material, in order to make it as dense as possible, but the combustion in guns was still so violent, and the erosion and strain upon the weapons so great, that its use was soon abandoned.

Simultaneous with the experiments made in Austria by Von Lenk, a very able and ingenious young man, then Mr. Abel, now Sir Frederick Abel, was experimenting on guncotton in England, and to him, more than to any one else, the world owes the perfection of manufacture and the introduction and maintenance in use of this important substance. He saw more clearly than any of his contemporaries or predecessors the necessity of thorough purification of the original cotton, freeing it of everything as nearly as possible, leaving pure cellulose. He also employed a much improved method for the thorough cleansing and freeing from acids of the finished product, and substituted cotton waste for cotton wool, thus materially cheapening the cost of the raw material.

Abel concluded that as cotton fibres consist, in reality, of small tubes, washing by ordinary methods, however thoroughly and long continued, would, after nitration, fail to extract the last traces of acid from within the tubes of the cotton fibre. He, therefore, after cleansing the nitrated cotton in a most thorough manner, resorted to finely pulping it, and then poaching the pulped material and impregnating with an alkaline solution. Abel's method produces an absolutely stable article, and his process is now universally employed in the manufacture of guncotton all over the world.

Abel was also the first to take any really rational step in the production of smokeless powder for guns. He prepared a mixture of soluble and insoluble guncottons, and then treated pellets, formed of the mixture, with a solvent of the soluble variety, thereby agglutinating the fibres of the insoluble with a collodion formed of the soluble.

Experiments made with this powder gave very promising results in a Martini-Henry rifle. Abel also experimented considerably with cartridges made of highly compressed guncotton, but the results of experi-

ments with this material were not very satisfactory.

In a patent secured in the United States in November, 1866, Abel describes a method of making solid masses of a mixture, in a fibrous pulped state, of soluble and insoluble guncottons, by subjecting the material to a solvent of the soluble guncotton, thus making the solvent serve as a binding medium for the insoluble guncotton, either in conjunction with or without pressure. In this way grains are formed, of sufficient density and hardness to adapt them for use in guns.

The import of this invention is better realised when we take into consideration the fact that the introduction and employment of modern smokeless powders has brought about a complete revolution in firearms and in projectiles. Abel's invention was as great a step as could well have been made in smokeless powders in advance of radical improvements in firearms. Smokeless powder could be made to-day exactly according to his above-mentioned invention which would give very good results, indeed, in the smaller calibre shoulder arms now in use; while none of the recent smokeless rifle powders could be made to give much better results in the old Martini-Henry rifle than were then attained by Abel with his powder, particularly if we except nitro-glycerine compounds.

PHOTO BY SARONY, NEW YORK

MR. HUDSON MAXIM

PHOTO BY LAWITZKY, BERLIN

DR. ROBERT C. SCHUEPPHAUS

Probably the next most important invention in explosive compounds leading up to smokeless powders was made by Alfred Nobel, and patented by him in Great Britain in 1875. This invention was for the gelatinisation of nitro-glycerine with pyroxylin, with or without other solvents or the application of heat. He states that the quantity of solvent should be varied with the degree of solubility of the guncotton; and as he mentions acetone as one of the solvents, and which is a solvent of tri-nitro-celluose, and the employment of slowing agents, or deterrents, to lessen the sensitiveness of the compound, among them fatty matters, to particularly adapt the explosive to military purposes; and as the chief essential difference between his nitro-gelatine and cordite and ballistite is one of proportions of the ingredients, we are forced to give him credit for hav-

ing anticipated these compounds. As Noble was thoroughly conversant with the work that had been done by Von Lenk, Abel and others, it is at least reasonable to presume that he thought of the employment of his nitro-gelatine compound as a propelling, as well as a blasting, agent; but there is no direct proof of this in the language of the patent.

Daniel Spill, also in 1875 patented a process for the production of tubes for military and other purposes from soluble

MR. HUDSON MAXIM LIGHTING HIS CIGAR WITH A STICK OF CORDITE TO SHOW ITS FREEDOM FROM EXPLOSIVE DANGER WHEN IGNITED

guncotton, gelatinised with ether and alcohol, or nitro-benzine.

Colonel Schultz, an Austrian artillery officer, made a sort of semi-smokeless powder in 1860, for sporting purposes, it being a form of nitrated cellulose, impregnated with nitrate of potassium or nitrate of barium. A smokeless powder was also, about the same time, made by Dittmar on pretty much the same lines.

In 1866 Messrs. Prentice & Sons, of Stowmarket, made a sporting powder from a pulped mixture of guncotton and un-nitrated cotton. Later, they made a granular smokeless powder, consisting of pellets of compressed guncotton, waterproofed by india-rubber varnish.

About 1880 Messrs. Reid & Johnson produced at Stowmarket a smokeless sporting powder of pulped soluble guncotton and nitrate of barium, the mixture being granulated by tumbling in a large pan to form round pellets, which were afterwards treated with solvents to harden them. The E. C. powder (Explosive Company's powder), first made at Stowmarket, in England, was an important advance in smokeless powders, and much credit is due to its inventors, Messrs. Reid & Johnson.

The French were the first to make smokeless powders from compounds of picric acid and picrates with nitro-cellulose and other substances.

The Peyton powder, manufactured by the California Powder Company, is a picric acid compound, and has given excellent ballistic results in the .30 calibre rifle and in the smaller quick-firing guns. According to Dr. Schüpphaus, who made an analysis of the powder, and whom I quote, "as much as the examination of a couple of grains can show, the powder seems to be prepared by making a dough-like mass of the guncotton and nitro-glycerine with ammonium picrate, and, apparently, some carbon."

In the latter part of the eighties the French Government produced a powder for small arms, known as the Lebel smokeless powder. Its method of manufacture was kept a rigid government secret, but it is now known that this powder was first made by dissolving soluble pyroxylin, later tri-nitro-cellulose, in sufficient solvent to cause the solution to flow, then drying in thin sheets, and cutting into small rectangular grains or laminæ.

The French powder thus made was exceedingly dense, hard, and hornlike; so much so, that it did not ignite readily, except with a very strong primer, and it would not burn through a sufficient thickness to permit of a granulation coarse enough to enable the use of the charges requisite to give desired velocities. Nevertheless, the most exaggerated accounts were current at the

time of results attained with this product.

The writer began the investigation of the subject of smokeless powders in England in the latter part of 1888. In December of that year he returned to America where he continued experimenting extensively with various guncotton compounds, but particularly with compounds of guncotton and nitro-glycerine.

At the same time Messrs. Abel and Dewar were working jointly in England on practically the same lines in the interest of the British Government. Messrs. Abel and Dewar were the first investigators in England to make a compound of gelatinated tri-nitro-cellulose and nitro-glycerine definitely intended as smokeless powder. They kept their methods secret until others, coming after them, had filed applications for provisional protection in Great Britain for methods of manufacture of practically the same compound. However, most of the patents then taken out proved worthless, owing to the already mentioned old patent for nitro-gelatine secured by Nobel in 1875.

After the issuance of the writer's first United States patent in September, 1889, Messrs. Abel and Dewar and Nobel filed interferences with it in the United States Patent Office. Nobel furnished sworn testimony that he had invented and manufactured the same material in Belgium more than two years ahead of the writer's application. As the claims of the writer's patent covered broadly the compounding of nitro-glycerine and guncotton of whatever grade or degree of solubility, by a volatile solvent, and afterwards evapourating the solvent, the writer saw that if he lost his case and Nobel won, the latter would have a virtual monopoly of the smokeless powder business in America. An exhaustive search was, therefore, made for references in both Great Britain and the United States, with the result that the already mentioned old English patent was found of Nobel himself for the manufacture of nitro gelatine. This the writer cited and showed, to the satisfaction of the Patent Office, that the same broadly anticipated all the respective claims, thus making the invention public property, and invalidating his patent and the applications of Messrs. Abel and Dewar and Nobel.

BURNING A STICK OF DYNAMITE

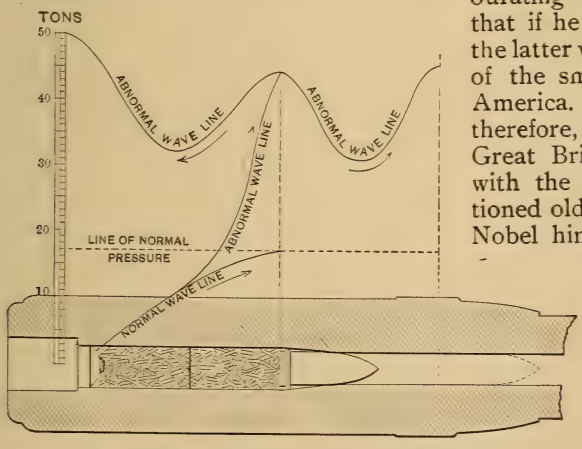


DIAGRAM SHOWING EXPLOSIVE WAVE ACTION IN A GUN

About this time the writer came to the conclusion that the high state of development of the processes of manu-

BURNING A GRAIN OF BLACK PRISMATIC SMOKY POWDER FOR A 10-INCH GUN

BURNING A GRAIN OF MAXIM-SCHUEPPHAUS SMOKELESS CANNON POWDER

facture of celluloid, as practised in the United States by the American Zylonite Company, was the key to a successful system of making smokeless powder, particularly for large guns. Prof. George M. Mowbray, the chemist of that company, informed the writer that they had experimented largely with castor oil in their pyroxylin compounds, and he suggested its employment in smokeless powder compounds of guncotton and nitro-glycerine.

It was thought by the early experimenters that guncotton, in whatever shape, even the hard colloid formed by dissolving and drying it, would burn too rapidly as guncotton, and would be likely to detonate. This was the primary reason for adding oil and other substances known as "deterrents" for the purpose of slowing combustion and for lessening susceptibility to detonation.

However, it was found that the hard guncotton colloid, instead of burning too rapidly, was too slow, and would not burn through a sufficient thickness of material to permit of coarse enough granulation to enable charges large enough to be employed to give requisite velocities without dangerous pressures.

The best of all softening agents is nitro-glycerine. The reason for the employment of so large a quantity of nitro-glycerine in cordite as 58 per cent. is to so soften it and increase the rapidity of combustion that rods or sticks of the material may be made large enough to reduce the initial area presented to the flame of ignition to a minimum per unit of weight.

The experience gained in the manufacture of celluloid has been of the utmost importance in the development of smokeless powders. In the early sixties Alexander Parkes, of Birmingham, and Daniel Spill, of London, afterward manager of the American Zylonite Company, in the United States, took up the subject of the manufacture of articles from a colloid formed from the dried solution of soluble guncotton. In the United States, J. A. MacLellan and John W. Hyatt carried the work still further, but the most important of all inventions on these lines was made by Daniel Spill in 1869, who discovered that a compound could be formed of soluble pyroxylin and camphor, which was plastic at seventy-five degrees Cen-

BURNING A CHARGE OF DU PONT BLACK SMOKY RIFLE POWDER

BURNING A CHARGE OF DU PONT SMOKELESS RIFLE POWDER

tigrade, and that camphor was a solvent of certain soluble varieties of guncotton. Thus, Daniel Spill may be termed the father of the celluloid industry.

About 1890 Nobel, following the clue of previous observations, that water assisted in the gelatinisation of gelatine-pyroxylin with nitro-glycerine, and being familiar also with the celluloid industry in Germany, invented a method of completely gelatinising gelatine-pyroxylin in an equal weight of nitro-glycerine in the presence of water between heated masticating rolls. The product he subsequently rolled into sheets between calendar rolls and cut into cubes of any desired size for use in guns. The writer was the first to introduce to the United States Government any form of smokeless powder, and likewise was the first to make smokeless powder in America.

Following these experiments, Dr. Robert C. Schüpphaus, formerly chemist of the American Zylonite Company, produced a smokeless rifle powder, and also a cubical powder for large guns from a gelatinised compound made from a peculiar grade of soluble pyroxylin (invented by him), nitro-glycerine and shellac, later substituting di-nitro-benzine for the shellac. About this time Dr. Schüpphaus made the important discovery of the peculiar property possessed by urea for giving perfect stability to pyroxylin compounds. Prior to this invention it was impossible to make perfectly transparent photographic films of celluloid, owing to partial decomposition of the compound under the elevated temperatures to which it was necessarily subjected in manufacture. By the use of urea, however, all this difficulty has been overcome, and such films are now produced as transparent as glass.

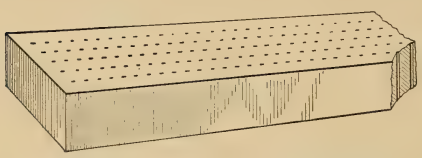
All the powders made by Dr. Schüpphaus contained urea. This invention has since been patented all over the world. Following the experiments made by Dr. Schüpphaus, one of his assistants succeeded in getting capital for continuing the work, and quite a stir was made at the time by the remarkable results produced by the so-called Leonard powder made by them, and which, in fact, was substantially the same compound that had been produced by Dr. Schüpphaus.

In 1889 the writer conceived the idea

of making multi-perforated smokeless powder grains in order to render them progressive in their combustion, thereby minimising the initial area to the flame and raising to the maximum the burning surface just before the complete consumption of the grain. The idea of making multi-perforated powder grains was not at that time broadly new, as already stated, except in its connection with the manufacture of smokeless powder, and the writer's improvement lay not so much in the idea of perforating the grains as in a practical method for their manufacture.

After experiments with smokeless powders had been taken up in earnest in the early nineties, the necessity soon became apparent of devising means of increasing the rapidity of combustion of colloidal compounds of guncotton, in order to permit of sufficiently coarse granulation to adapt smokeless powders to large guns. The writer's method was to multi-perforate the grains. Sir Frederick Abel sought the same end by increasing the percentage of nitro-glycerine, producing cordite, while the French added nitrate of barium to guncotton colloid and rolled the mixture into long, flat strips.

In 1893 Dr. Robert C. Schüpphaus and the writer united their forces and



SECTION OF A GRAIN OF TRANSVERSELY PERFORATED MAXIM—SCHUEPPHAUS CANNON POWDER

inventions, and have been working together ever since. They undertook from the first to develop a smokeless powder on the lines of celluloid manufacture. At first they experienced great difficulty in manipulating tri-nitro-cellulose and producing grains from it which would not warp and crack all to pieces in drying. It was necessary to employ such a large quantity of solvent to render the guncotton plastic that the shrinking and drying was so great as to make it quite impossible to produce grains of sufficient size for use in large guns. They also experimented extensively with numerous compounds of nitro-glycerine and soluble pyroxylin, as well as with compounds of nitro-glycerine and tri-nitro-cellulose.

Happily they hit upon the expedient of adding a small admixture of gelatine pyroxylin to the tri-nitro-cellulose. This resulted in a most important discovery, that the gelatine pyroxylin had a similar effect when employed in connection with a small proportion of acetone on tri-nitro-cellulose of rendering the latter plastic, and susceptible of being moulded into grains of any desired size or shape, under heat and pressure, as camphor in celluloid. It was found that this could be done with so little of the volatile solvent that the grains shrunk but very little, and did not warp or crack, while at the same time the tensile strength of the compound was much enhanced and the product made tougher.

It was found also that the same properties were manifested when nitro-glycerine was added to the compound, in whatever proportion. After numerous experiments to determine upon the best compound to employ, it was decided that a certain percentage of nitro glycerine should be added, and that the proportion should not be less than 9 per cent.

In 1894 the writer applied for a patent on an invention which has since been patented all over the world,—a process and a die for the manufacture of multi-perforated smokeless powder grains, whereby the dense and stiff, though plastic, material, with a minimum of solvent, could be practically and rapidly formed into multi-perforated grains of any desired size and with any desired burning thickness between the perforations to adapt the grains to use in cannon of all sizes.

The Maxim-Schüpphaus smokeless powder, produced by the joint efforts of Dr. Schüpphaus and the writer, has now been adopted by the United States Government, and is the service powder of both the army and the navy. This powder has the advantages over any

other that has yet been produced in the respects that it is more stable, harder, and will stand rougher handling, that it is progressive in its combustion, and capable of producing higher ballistic results than have ever been attained by any other compound or other form of grain.

The Maxim-Schüpphaus smokeless powder is now being manufactured by Messrs. E. I. Dupont de Nemours & Co., of Wilmington, Del., who have purchased the United States patents.

In the popular mind many erroneous impressions prevail concerning the combustion of gunpowder and the meaning of the word explosion. There are two ways in which explosive compounds are consumed. One is called detonation, which is a form of reaction, so rapidly propagated through the explosive body, that it is termed an explosive wave. By the other method, the explosive body is burned from exposed surfaces, and is merely a form of rapid combustion.

Detonative substances are usually termed high explosives. Those which burn from surfaces may be termed combustive explosives. Combustive explosives, requiring an appreciable time for their consumption, are adapted to use as gunpowder by giving the projectile time to be moved forward in the bore of the gun before the complete consumption of the charge, thus providing space for the products of combustion, and obviating dangerous pressures.

The best form of gunpowder grain is one whose consumption will be completed at the instant before the projectile leaves the gun, and one so formed as to present the minimum surface to the flame of ignition, and the maximum surface at the instant before complete consumption. Such forms of grains produce what is called progressive combustion, by which the pressure is well maintained behind the projectile throughout the entire length of the gun. Such progressive combustion is best secured by multi-perforating the grains, as is done in the Maxim-Schüpphaus smokeless powder.

Explosive compounds contain sufficient oxygen for their own combustion, and do not require atmospheric oxygen. Black gunpowder is a mechanical mixture of combustible substances, usually sulphur and charcoal, with some salt rich in oxygen, such as nitrate of potassium, termed saltpetre It requires about 75 pounds of saltpetre to supply the oxygen for burning 10 pounds of

BURNING SMOKELESS CANNON POWDER UNDER WATER

sulphur and 15 pounds of charcoal. When black powder which has been pressed into hard cakes, or prisms, is fired in a gun, the small particles of saltpetre and sulphur at the surface instantly fuse and combine with one another and with the adjacent particles of charcoal, forming sulphate and carbonate of potash, setting free carbonic acid gas, nitrogen and carbonic oxide. The sulphate and carbonate of potash may be termed the ash of the gunpowder. These solids constitute about 56 per cent. of the total weight of the products of combustion; only about 44 per cent., therefore, are gaseous.

By pulverising the several ingredients of black gunpowder very finely and compressing them lightly to form grains, a quick powder is obtained. If com-

pressed very hard, the powder is slower. If the charcoal be only partially burned, or, rather, roasted to a chocolate colour, and the mixture compressed hard into prisms, we have what is known as brown prismatic powder, which burns the slowest of all forms of smoky powder. A grain of this material, ignited in the open air, will often actually go out of its own accord. It requires to be burned under great pressure in order to be rapidly consumed.

Smokeless explosives are compounds in which the oxygen is in chemical union with the combustible elements,—carbon and hydrogen. Associated together in the same molecule is nitrogen, an element of weak affinities. Such bodies, when liquid, like nitro-glycerine, are easily detonated. Even a light blow is often sufficient to cause the oxygen to combine directly with the combustible elements to the exclusion of the nitrogen, by which the liquid is instantly converted into gases. This accounts for the rapidity of explosion and great power of certain high explosives. Guncotton consists of an infinite number of small fibres in the form of tubes, whose walls, although consisting of a hard colloid, are so very thin that a compressed body of the material is readily detonated.

If the guncotton, however, be dissolved in a suitable solvent and dried, a very hard and hornlike substance is formed, which, if made into grains of a suitable size, is absolutely safe against detonation under all conditions to which it may be subjected as gunpowder.

A pure guncotton colloid, however, is too hard, and will burn through too small a thickness of material to adapt it to use as gunpowder, because it requires such fine granulation that full charges cannot be employed without giving dangerous pressures. If, however, a small quantity of nitro-glycerine, say, 10 to 15 per cent., be added to the guncotton solution, the grains will burn much faster and consequently may be made larger, and more of the material may be put into the gun without exposing so much burning surface as to be dangerous. The larger the quantity of nitro-glycerine that is added, the more rapid will be the combustion, and the larger may be the grains. The British Government have found it necessary to employ as much as 58 per cent. of nitro-glycerine in order to secure sufficiently rapid combustion to adapt cordite to large guns. If, however, the smokeless powder compound be multi-perforated, as is done in the Maxim-Schüpphaus powder, the material may be made much harder, on account of the reduction of initial burning areas per unit of weight.

The products of combustion of smokeless powder being practically all gaseous, it is easy to understand why it is so much more powerful than black gunpowder, only 44 per cent. of the products of combustion of which are gaseous. Smokeless powder is more economical than black powder, although costing twice as much. During the last six years the United States Government has conducted exhaustive experiments with the Maxim-Schüpphaus smokeless powder in the form of multi-perforated cylinders, and, as already stated, it has been adopted in both branches of the service.

In the report for 1896 of the Chief of Ordnance, United States Army, it is stated:—"All things considered, the perforated cylinder or disk, proposed by General Rodman many years ago, and recently revived in the Maxim-Schüpphaus powder, appears to me to be the most suitable and promising form for the colloidal smokeless powders."

There is a limit, however, to the length of which longitudinally perforated grains may be made; for if the grains be made too long, and the perforations too small, and fired under high pressures, the excess of pressure within the perforations, owing to the greater rapidity of combustion there than upon the outer surfaces, is likely to disrupt them. The higher the pressure employed, the shorter should be the grain.

A preferable form of grain is that shown on page 246, having transverse perforations. Such a grain, made from one-third to one-half the length of the powder chamber, and even, in some

cases, its whole length, is nearly an ideal form for securing the maximum benefit of progressive combustion. The perforations are so short as to preclude any danger of disruption from interior combustion, at the highest pressures which can be employed in guns.

The transversely perforated grain has also the advantage that it provides straight channels for the passage of the products of combustion through the charge. When prismatic grains or short sections of cylinders are employed, it sometimes happens, when ignited from the rear, that the charge is thrown violently forward into the narrow neck of the powder chamber at the projectile seat, setting up great local pressure with disruption of the grains at the forward end of the charge, increasing enormously the burning areas, with corresponding still higher mounting of the pressure at that point. This sets up a reactionary wave toward the rear of the gun, whose momentum, combined with the rapidly evolved gases of the burning charge, often raises the pressure beyond the strength of the gun. It is probable that the disastrous explosion last March of the 10-inch gun at Sandy Hook, while undergoing trial by the United States Government, may be accounted for in this way.

Current Topics

In view of the attention that has, of late, been devoted to accidents from the bursting of fly-wheels, and the various designs that have been proposed to prevent them, it seems a bit strange that only passing notice should have been given to wire-wound rims for such wheels. Several wheels of this character have been turned out and have been at work with good results for a sufficiently long time to take them beyond the purely experimental stage, but still they have remained isolated examples of a possibly excellent type. Cost of construction may have something to do with this, for their cost was, in all likelihood, comparatively high. But if they thoroughly accomplish the attainment of safety, as they seem to have done, they represent an investment quite as profitable as any that might be made with the saving in cost of a wheel of ordinary construction and the usual uncertainties of behaviour. What a fly-wheel rupture is capable of doing in the wrecking of its surroundings has been shown by a long list of costly accidents. The wire-wound fly-wheels that have been used thus far have been of the home-made variety; that is to say, they have been made by their users, and none, so far as is known, have been

offered for general service, so that possibly one additional reason why there are so few of them may be lack of advertising and lack of information, to any appreciable extent, of their good points.

It is a noteworthy fact that, in spite of potassium cyanide being handled in such large quantities as it is to-day in gold-mining operations, principally, perhaps, at the various Witwatersrand mines in South Africa, cases of cyanide poisoning are rarely heard of. The danger, however, always exists, and one such accident which occurred not long ago through a glassful of the deadly stuff being, in some way, mistaken for water, has prompted a communication by Dr. J. Loevy to the Chemical and Metallurgical Society of South Africa, in which he explains the rapid deadly action of cyanide as being due to the fact that, owing to acid always being present in the stomach, free hydrocyanic acid is immediately formed, which, by entering at once into the blood, acts as a strong blood poison. Any antidote administered, calculated to counteract the poison in the stomach itself (ferric or ferrous salts) will have no effect whatever, as many instances have shown. Very litt'e is known of the action of hydrocyanic acid in the blood, but authorities agree on this point that hydrocyanic acid deprives the tissues of their capability to absorb oxygen, even if this latter is present in a large quantity. Cyanide poisoning is, therefore, according to Kobert, a suffocation in the presence of oxygen. It follows from this that, in the case of cyanide poisoning, an antidote can be expected to have effect only if immediately administered and incorporated into the blood by subcutaneous injection. The only chemical which, according to practical experience, can be considered for this purpose, is peroxide of hydrogen. Kobert was the first to draw attention to this, and, as the result of numerous physiological experiments he recommends the subcutaneous injection of a 2 per cent. solution of peroxide of hydrogen as an almost infallible means of counteracting the effect of cyanide, provided, of course, that the injection is made immediately, or very shortly after, the introduction of the poison. Only lately several cases have been reported in Germany where human lives have been saved by this method of treating cyanide poisoning.

Dr. Loevy very properly makes the point that provision for immediate rational help against cyanide poisoning should exist in every cyanide plant, and suggests, accordingly, that a certain quantity of pure peroxide of hydrogen, distilled water, and a Pravarz syringe should be kept in every cyanide plant, and that all workmen on the plant should be made acquainted with the method of preparing a solution of the required strength and of injecting it subcutaneously,—a practice which any sensible man can readily acquire. The peroxide of hydrogen should be kept in small bottles containing about ½ oz., with tight-fitting glass stopper, and kept in the dark to prevent decomposition. Considering that provisions have been made in all large industrial establishments to render first surgical aid in the case of accident, Dr. Loevy thinks that a provision as suggested above against cyanide poisoning is just as well called for in cyanide plants.

Among the curiosities preserved in the old State Library at Albany, N Y., U. S. A., none have attracted more attention than the few links of the monster chain which did service in the days of the American Revolution to prevent the progress of the British ships up the Hudson River. The great chain, with links more than two feet in length, was stretched across the river near West Point, and remnants of the unique blockading material are preserved in various parts of the United States. Apropos of this, the *Bulletin*, of the American Iron and Steel Association, remarks that

while bombs, mines, fortifications, and torpedoes have taken the place of the chain as a barrier against hostile ships, monster chains are still manufactured in large quantities, and one firm is now making a chain, the links of which are formed out of rolled steel, three inches in diameter. Welding by electricity, winding the metal rod from which the links are made around a mandril, cutting the pieces by machinery and joining them by blows from powerful steam hammers, binding the links and testing the completed chains with hydraulic pressure, are all modern processes in the chain-making industry, but the great chains used in the shipbuilding trade are made much as they were made many years ago. The commercial article, as turned out by American makers, ranges from three-sixteenths of an inch to one and three-quarter inches, and no chains are put on the market unless they have been tested. Thus a three-sixteenth-inch chain of five pounds average weight per foot is guaranteed to hold 700 pounds, and the better grades as high as 900 pounds. A one-inch chain which weighs about ten pounds to the foot will hold 24,000 pounds, and a chain with links of one and three-quarter inches, weighing thirty-one pounds to the foot, is supposed to resist 71,600 pounds, and the best quality of the same size chain is marked "Proof 90,575 pounds."

EXTREMELY tall business buildings, sky-scrapers, as they have been familiarly dubbed, have recently afforded opportunity for a number of interesting tests by the fire department of New York City, with the resultant conclusion that instead of being a source of fire danger, as had begun to be suspected, such buildings would really be a great protection to the older ones, provided they were suitably equipped with stand-pipes and connections for the apparatus of the department. In this proviso, however, is found a good indication of a few of the things which are lacking in the mechanical equipment of the modern tall building. With very few exceptions its lay-out of pipes for fire-fighting purposes is totally inadequate. The pipes are too small, to begin with, and the many valves interposed along their line, —and valves, too, of an undesirable kind,—further cramp their serviceable area to such an extent that the fire-streams, which, according to original expectations, should have been very respectable ones indeed, show themselves as feeble little squirts when called upon for serious business. It is quite immaterial whether this is due to careless or incompetent engineering, or to ill-advised economy in equipment; the fact remains that the piping is often almost worse than useless in that it tends to create a false sense of security. Ample pipe diameters and a clear waterway are requisites of the first importance; with them, and, of course, with a correspondingly ample water supply, a tall building stand-pipe system ought to prove, as the tests mentioned have indicated, a good safeguard against fire for the building itself and for a goodly portion of its surroundings.

CONSIDERING the fact that Americans have been accustomed to plume themselves on having the largest industrial concerns in the world, and that the Germans and the French are showing an increasing disposition to talk somewhat boastfully of such establishments as Krupp's, at Essen, and Schneider's, at Creusôt, the London *Iron and Coal Trades Review* took occasion recently to intimate that, after all, Great Britain in in such things does not lag far, if at all, behind. While the largest number of blast furnaces, for example, possessed by a single concern in the world, is owned by the Austrian Alpine Montan Gesellschaft, who have a total of thirty-two furnaces, most of them are not of modern construction, and work with charcoal fuel. Of more modern furnaces the largest number owned by a single firm is twenty-six, this being the figure reached by William Baird & Co., of Glasgow, who own the works at Gartsherrie, Eglinton, Lugar and Muirkirk,

in Scotland. These are unitedly equal to an outpnt of 400,000 tons a year, or about one-third of the total pig iron production of Scotland. Next to W. Baird & Co., come Messrs. Bolckow, Vaughan & Co., of Middlesbrough, with a total of twenty-four furnacs, equal to an annual output of 750,000 tons of pig iron, if all were in blast, and situated at the five works of Eston, Cleveland, Lackenby, South Bank and Middlesbrough. The capacity of pig iron output in both of these cases is below that of some American firms, although the number of furnaces is larger. In South Wales and on the West Coast the largest plants are owned by the Dowlais and the Barrow companies, which each possesses fourteen furnaces.

With the labours of the Peace Congress at The Hague fresh in mind, it is interesting to consider what would happen in industrial engineering should universal peace ensue and warlike preparations cease. Setting aside, for the moment, all consideration of humanity, Christianity, and civilisation, or whatever else there may be of powers which make for peace, the *Engineer*, of London, recently discussed the question whether the state of war in which we habitually live is not rather a benefit than a disadvantage to the world, and what effects would follow a reign of universal amity, trust, and good will. Presuming the outcome of the Peace Conference to be a decision that no nation was to be allowed to make its naval and military strength greater than it is now, the *Engineer* considers the effect on the industrial welfare of Great Britain, for example, after the following manner:—In the royal dockyards there are employed about 27,000 men, receiving in wages £1,960,000 odd per year. At Woolwich and elsewhere there are employed some 25,000 hands, earning about £1,500,000 odd. To these should be added the persons employed in powder factories and manufacture of other stores. If we place the total expenditure on wages alone, paid direct to persons engaged in manufacture in the employ of the Government, at £4,000,000 per annum, we shall not be over the mark. When we come to the consideration of private establishments, the difficulty of estimating the wages earned is much greater, as there are no published statistics on which to reason, and the number of firms which undertake work for home as well as foreign governments is very large. We shall certainly not be over the mark if we estimate it at 150,000 men, and probably far below it. Taking the wages earned at an all-round average of £70 per man per annum,—about the dockyard rate,—we have an expenditure of £10,500,000 per annum in private works on naval and military *matériel*. Adding this to the Government expenditure estimated above, we have a total of annual wages spent in Great Britain in this direction amounting to certainly not less than £14,500,000.

In this estimate only those have been considered who are employed on the manufacture of finished articles. It is almost impossible to arrive at any clear notion of the number who earn their bread in supplying the raw or partly finished materials for these. There are sailors, railway servants, miners of coal, and miners of metal, rolling mill men, and a host of others. Then there are engineers who provide costly tools for the manufacture of ordnance and ordnance supplies, and all those who are engaged in the preparation or manufacture of the personal appurtenances of the army and navy. It is readily seen that to form even a remote conception of the number who take indirectly the money of the British and foreign governments is out of the question. One can only say that the figure is very large. Possibly, not less than a million persons in the British Isles gain their entire income, or some fraction of it, in this way. It is sufficient for this purpose, however, to consider those only who are directly employed, over 200,000 persons. If, now, the addition of entirely new material

were given up, or were limited only to the manufacture of what was required to replace loss or wear, what number of hands would be needed and what wages expended? One-tenth of the whole number now employed would probably prove sufficient, and could the thing come suddenly upon us, 180,000 persons would be thrown out of work, to say nothing of the unestimated number whose employment is dependent on the work of the 180,000. To form a conception of what this means, it may be pointed out that to give employment to that number of persons would require the establishment of ten new industrial establishments as large as that at Elswick, for example, or the provision of employment for the industrial population of a city as large as Manchester or Birmingham. In the course of time readjustment would certainly take place, but many years would be needed for its completion, and the reign of international peace would probably be seriously marred by internecine industrial struggles of great magnitude, and even the peace itself threatened, for it is not unlikely that the restlessness of the people, consequent upon lack of employment, would bring them to that state of mind which lightly regards the possibility of war.

MOST big nations have profited by warlike preparations, and most of them have something to lose by their cessation. The building of fighting ships has taught us naval architecture; and the construction of guns and armour has led to great advancement in metallurgy; it has taught us to work accurately, it has provided us with many beautiful tools, and has led to engineering developments greater than any produced by the peaceful arts.

A VERY good illustration of the saving in time and money and the consequent reduction in the price of an article which may be effected by machine work as compared with hand labour, is furnished in the department devoted to the japanning and drying of armature discs after they have been slotted, at the mammoth establishment of the General Electric Company at Schenectady, New York. It was formerly the custom to japan these discs by hand and then hang them up in rows to dry. This process took about forty-eight hours. Now the whole thing may be seen accomplished in half a minute by means of two rollers, placed opposite each other like printers' ink rollers, behind which an endless latticed conveying belt travels. The discs are fed into the rollers and receive the necessary amount of japanning on both sides, then fall on the belt and are carried between compressed air nozzles which dry them in a length of twenty feet or so. When the discs reach the end of their travel, they fall into a suitable receptacle, thoroughly dried and ready for assembling.

PROFESSOR LANCIANI, according to *Architecture and Building*, has made some curious discoveries in reference to the building laws in force in ancient Rome, from which it would appear that the extravagantly high buildings which it is customary now to consider as exclusively American in origin, were quite well known in Rome, and were the subject of restrictive legislation for much the same reasons that they are objected to to-day, namely, dangers from fire, danger from deterioration of the strength of the structures themselves, complaints of the darkened streets, and others. Professor Lanciani, for example, has found frequent allusions among the Roman historians to the enormous height of the tenement buildings of Rome; but no definite figures appear to have been given until the days of Augustus, when a law was promulgated which fixed the height of new structures at 60 feet on the street front, without making any allusion to the height of the rear. It is, however, known that, in the rear, these tenement buildings rose often several stories higher than in the front, so that from a distant height, as

from the top of a temple which commanded an extensive view, a row of tenement buildings in Rome presented the appearance of a terrace,—highest in the rear and descending by stories toward the front. The law of Augustus applied to new buildings, respect, then as now, being shown for investments already made.

THE number of stories on the street front of these Roman buildings was generally ten or twelve, with fourteen or fifteen in the rear. The lowest stories were 8 or 10 feet in height, but from accounts given by writers of that time, the stories would appear to have gradually diminished as their height above the ground increased, so that the topmost tenants lived in quarters where very often they could not stand erect. That the stories were sometimes less than 5 feet high is shown by the discoveries in Pompeii, where, in a house inhabited, presumably, by poor tenants, a story of 4 feet 3 inches has been discovered. This was a living room, too, for in it were found all the articles which pertained to Roman housekeeping,—cooking utensils, beds, stools, mirrors, combs, brushes and other things, which, with the bones of the family, furnished indisputable evidence that the room had been occupied. That the tenement-houses of Rome towered at least 100 feet above the street in front, and 125 to 130 feet in the rear, is certain, for the promulgation of an edict limiting the height to 60 feet in front, indicates that this height had been so greatly exceeded in so many cases that the public safety was believed to be imperilled. How many stories were contained in these tenements is conjectural, but if the upper stories were no higher than that of the house in Pompeii, the Roman tenements may have contained as many or more stories than the modern office building.

WORCESTER REED WARNER

A BIOGRAPHICAL SKETCH

By Edward W. Morley

TO the machine tool world the firm name of Warner & Swasey has long stood as a guarantee of general excellence, and among engineers the members of the firm individually have, similarly, for many years, occupied positions of distinctive prominence.

Mr. Warner, the senior member, and one of the past presidents of the American Society of Mechanical Engineers, of whom an excellent portrait appears in this issue, was born at Cummington, Mass., in 1846. He was descended from *Mayflower* stock, and from his ancestors, who included colonial and revolutionary captains, he inherited a strong physique, a clear intellect, and unswerving principles.

These are the foundation on which have been built, not only such reputation as belongs to the subject of this sketch, but also the fame of some of the most illustrious of our countrymen. The life of a large family on a New England farm is one of labourious activity for all concerned, but in this case the burden was lightened by tender affection and noble example. An uncle, the rector of an Episcopal church at Providence, was a man of scholarly ways, and, after his early death, his library found its way to the old homestead. There its treasures of classic

English were eagerly read and read again, stimulating that thirst for higher education which only one of the children was to obtain, and that only by the help of her brother Warner after he had abandoned his own hope of it and started on a career of modest self-support.

His tastes, from early childhood, were in the direction of mechanical and physical science. Every moment which could be spared from his many duties was spent in reading, study, and experiment, so that, as a boy, he achieved a local repute for ingenuity and insight by mending clocks and farming implements, building dams and sawmills, making barometers and spy-glasses, and keenly observing the physical phenomena which came under his notice.

It was after his first reading of Hugh Miller's "Testimony of the Rocks" that his pious grandmother, having heard, with horror, his statement that the world was not made in a week, expostulated with his parents for allowing him to have such pernicious books. Fortunately they sympathised too much with his tastes to put any obstacles in the way of his scientific studies. It was his mother, in fact, who first turned his childish eyes upward to the stars, taught him their names and constellations, and inspired him with that delight in astronomical lore which was to have such important results in after life.

At the age of nineteen, leaving an elder brother to inherit the farm, Worcester Warner went to Boston to seek employment. Possibly his inexperience saved him from any sense of doubt as to his future. An advertisement for a young man to learn mechanical drawing led him to join a long line of applicants, and a tricky question in mechanics, answered incorrectly by all the rest and correctly by him, secured for him the coveted opportunity in the engineering office of George B. Brayton. This office was shortly afterwards removed to the company's works at Exeter, N. H. There, in the person of a shopmate from Exeter, the Cummington apprentice found his future partner, Mr. Ambrose Swasey.

Three years were spent here in close application to work by day and study by night, with but little diversion other than that afforded by wholesome companionships and by connection with an active church. At the end of this time the two young men, ambitious for wider opportunities, left Exeter together for Hartford, and readily found employment in the works of Pratt & Whitney. Promotion followed rapidly, and both were soon independent contractors. With easier circumstances, Mr. Warner, while continuing his studies in several chosen lines, permitted the social side of his nature to manifest itself, and became prominent in various literary, scientific, and social circles.

After several years of such pleasant relations, varied by travel in Europe, Mr. Warner decided to advance his business interests by moving westward in company with Mr. Swasey. In 1881, having purchased a convenient site and erected the necessary shops, the firm of Warner & Swasey entered upon its successful career in Cleveland. A happy combination of business ability and mechanical genius with habits of upright dealing and living had its natural effect in speedily winning to the young men the cordial respect and regard of their associates. Their machine tools took at once the high stand which they now maintain in the markets of the world, and which makes the reputation of the firm in the line of mechanics.

In the scientific world they are equally well known as the makers of most delicate and at the same time large and complicated astronomical instruments. During his life in Hartford Mr. Warner had familiarised himself with the making of telescopes, then largely in the hands of Alvan Clark, of Cambridge, and of Sir Howard Grubb, of Dublin. Both of these men he knew and visited. Having purchased first a 6-inch, and afterwards a 10-inch, object-glass of Alvan Clark, he mounted them equatorially for his own use. These telescopes were afterwards sold

to Western colleges, and are still serving their purpose.

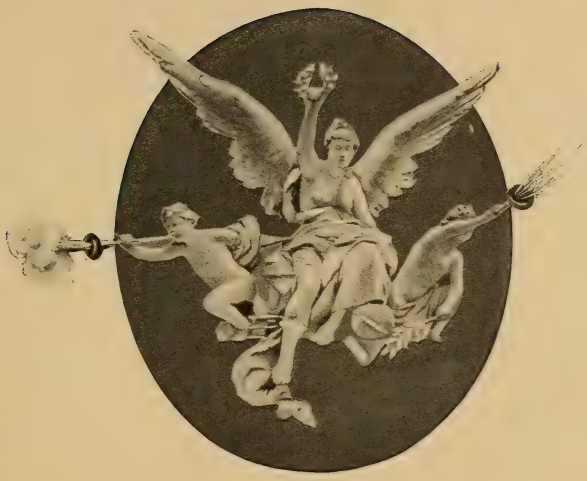
It was the opinion of Mr. Warner that telescope mountings, as then made by instrument-makers, lacked certain desirable features which could be imparted by mechanical engineers possessing ingenuity and good taste. While showy with lacquered brass, they seemed to him awkward in construction and crude in mechanism. It was this fact which induced Messrs. Warner & Swasey to enter the field in which today they are unsurpassed. They had already made a goodly number of equatorial mountings for telescopes of improved design when, with Grubb, the Repsolds, and Clark, they entered the competition for the equatorial mounting of the great Lick telescope. They secured the contract by reason of evident superiority in mechanism and design. With this vast instrument the mounting of a telescope entered the domain of mechanical engineering, and the making of such mountings became a regular part of their manufacturing. Their instruments are to be found in colleges and private observatories all over the country. Some of the best known of these are the equatorials of the observatory of Carleton College, of the Dudley Observatory, of the Flower Observatory at the University of Pennsylvania, of the United States Naval Observatory, and of the Yerkes Observatory. To these may be added instruments of yet greater delicacy and precision, such as meridian circles, alt-azimuths, zenith telescopes, and the like. The necessary graduation of the circles for such instruments has been done on a circular dividing engine of their own construction and design, with results, it is believed, more accurate than ever before attained.

The great equatorial, meridian circle, and other splendid instruments to be found in the Naval Observatory at Washington are but a small part of what the firm of Warner & Swasey has furnished to the government. Sextants, gun-sights, range-finders, and field telescopes, of improved design, have replaced many foreign types previously in use, and have played their modest part in winning recent victories.

In this instance, at least, the prophet is not without honour in his own country, for Mr. Warner is an acknowledged leader in his own community, active in all that makes for good citizenship, and prominent in commercial, educational, social, and religious affairs. Besides many lesser connections, he is a director in some of the largest banks of his city; past president of its Chamber of Commerce; trustee of the Western Reserve University, of the Case School of Applied Science, and of the Cleveland School of Art; and has served a term as president of the American Society of Mechanical Engineers, of which he is a charter member. He is a member of the Rowfant Club, of the University Club, and of the Civil Engineers' Club, of which he is a past president.

In 1897 the University of Western Pennsylvania conferred on him the somewhat unusual degree of Doctor of Mechanical Science (Doctor Scientiæ Mechanalis), and he is a Fellow of the American Association for the Advancement of Science, a member of the British Astronomical Society, and a Fellow of the Royal Astronomical Society.

Mr. Warner has been a wide and keenly observant traveller in almost all sections of this country and of Europe, and his home contains many interesting mementos of these journeyings. His wife and two young daughters complete the family circle. It is, perhaps, in his home and with his close friends that Mr. Warner's attractive personality is at its best, yet for his associates and acquaintances everywhere he has a message of cheery optimism, a kindly sympathy, and a ready helpfulness which fully justify the popularity which he enjoys.



THE ELECTRIC RAILWAY NUMBER

CASSIER'S MAGAZINE

IN the history of engineering achievement there is nothing aptly comparable to what has been accomplished in electric railway development. In the short period of about ten years which span the life of commercial electric railway work, phenomenal results have been obtained, and from the few struggling lines of the late eighties the growth has been such that to-day there are in the United States alone more than 40,000 electric cars, running over nearly 15,000 miles of track, and yielding profitable returns on the enormous capital investment of one thousand five hundred million dollars,—a magnificent enterprise considered from whatever point.

The wide-spread interest in the field, and its importance in a business as well as an engineering sense, prompted, over a year ago, the publication of a special issue of CASSIER'S MAGAZINE in which should be embodied everything about electric railways that would appeal to the engineer, the capitalist, and the public generally. Some of the foremost engineers in the electric railway field were, therefore, secured as contributors, illustrations were gathered from all corners of the world, and the final outcome has been this volume,—a text-book on electric railway engineering which, it is hoped, will prove of interest and value to all.

NEW YORK, August, 1899

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THE ELECTRIC RAILWAY NUMBER

OF

CASSIER'S MAGAZINE

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Electric Railway Number

CASSIER'S MAGAZINE

VOL. XVI AUGUST, 1899 No. 4

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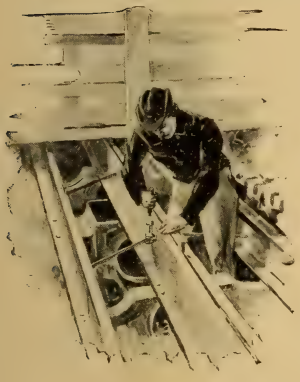
THE LATEST DEVELOPMENTS IN ELECTRIC CONDUIT RAILWAYS

By F. S. Pearson, Chief Engineer of the Metropolitan Street Railway Company, New York



IT would be wearying and serve no purpose, except to point out the enterprise and courage of the men, who in the face of great obstacles have developed underground conduit railway traction to its present high state of perfection, to rehearse the long list of failures connected with attempts to propel cars by means of cable and underground electric currents. Suffice it to say that they were due entirely to faulty construction, since experience has demonstrated that both methods are practicable when installed on lines of sufficient strength and stability.

Owing to imperfect design and insecure construction in these first attempts, conductor bars fell out of alignment and grounded, conduits and vaults collapsed, slots closed, and there arose, in consequence, so many complications that it was firmly believed by those interested in street railways that an underground conduit electric system could not be made operative.

The history of electric traction is in some respects similar to that of the electric telegraph. In the first efforts to transmit messages through wires, it was considered necessary by the promoters to bury the wires in the ground, and it was only after the failure of this method that it occurred to those interested in the first lines, that the wires could be strung on poles and thus do away with the troubles which had been experienced through leakage of the current to the ground when the wires were buried. When it was once proven that messages could be transmitted through aerial wires, the extension of the telegraph was rapid, and it was many years before the question of putting telegraph wires underground was again considered.

In Europe the question of underground telegraph wires came up for solution much earlier than in the United States, because of the greater objection there by the public to overhead wires. Furthermore, the advantage, in time of war, of having telegraph lines in the country buried and hidden from the enemy led the German and French governments to early study and perfect means of underground signalling.

The early inventors working upon the problem of electric traction felt that the only feasible method by which to operate the cars would be an underground system. It was not considered possible

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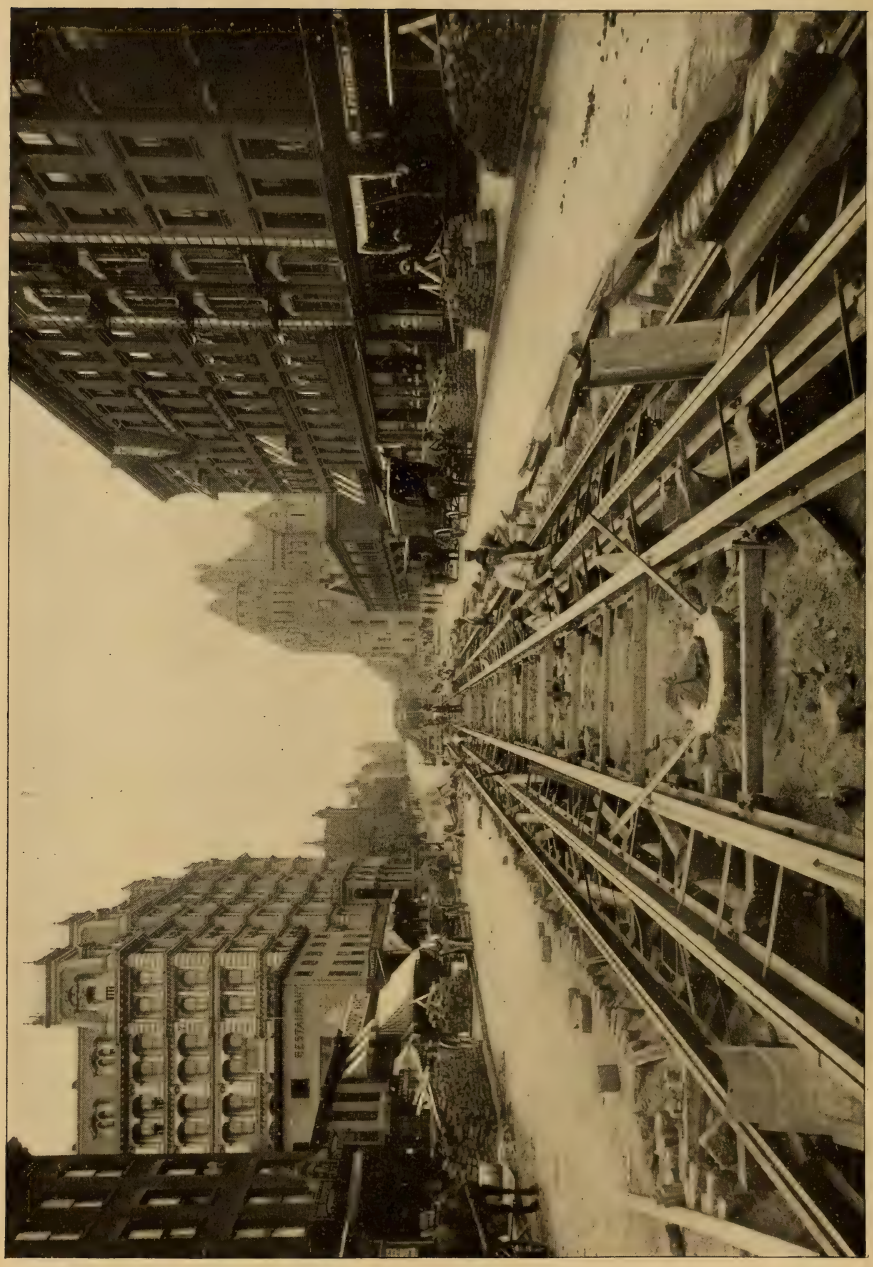
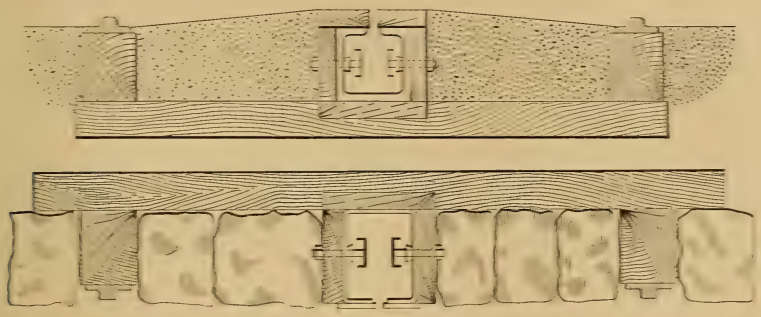
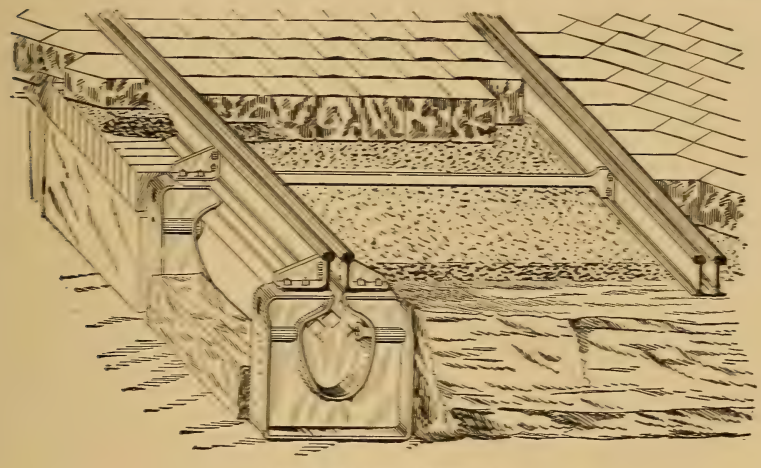


PUTTING IN CONDUIT LINING IN A NEW YORK STREET

to erect overhead lines which would be sufficiently secure and unobjectionable in city streets. The insulating material and appliances in the early days of electric railroading were so imperfect, both in quality and design, that it was difficult to construct overhead lines in a sufficiently substantial manner to guard against falling wires and consequent danger to the public and trouble in the operation of the road. Furthermore, most of the overhead line materials then available were very clumsy in design, and the overhead lines were necessarily unsightly, especially at curves and intersections.



SOME EARLY CONDUIT SECTIONS PUT DOWN AT CLEVELAND, OHIO, U. S. A., IN 1884



THE BUDA-PESTH CONDUIT

These early workers recognised that the underground system must be much more costly, but notwithstanding this, the urgency was felt to warrant the outlay, and many expensive attempts were made to construct conduits for the operation of electric cars. It would be tedious to describe the various attempts in this direction, all of which proved abortive from one cause or another. Through these failures, however, experience was gained and the conduit was improved, and without doubt the conduit would have been developed into a commercially operative system at that time if the overhead trolley had not offered a much cheaper and perfectly practicable alternative method.

One of the earliest attempts to build and operate a conduit road on a commercial scale was that of the Bentley-Knight Company, in Cleveland, O., in 1883. This road was about a mile and a half long and was operated until the fall of 1885. The service was not sufficiently satisfactory to warrant a contin-

LAYING YOKES AND INSERTING TIE-RODS FOR ONE OF THE NEW YORK CITY CONDUIT RAILWAYS

uation of the operation. The Bentley-Knight Company afterwards constructed a similar conduit in Allegheny, Pa., which was operated until displaced by the overhead trolley. Probably the most pretentious effort to solve the underground problem was carried out in Boston by the same company in the years of 1888 and 1889.

The illustrations on the preceding page show the general character of the Cleveland construction, and it is interesting to observe how little the general design differs from that finally adopted and used successfully in Buda-Pesth, and, later, for more modern installations. It is evident that the success of the latter is due to perfection of details in design and construction, rather than radical changes in general design.

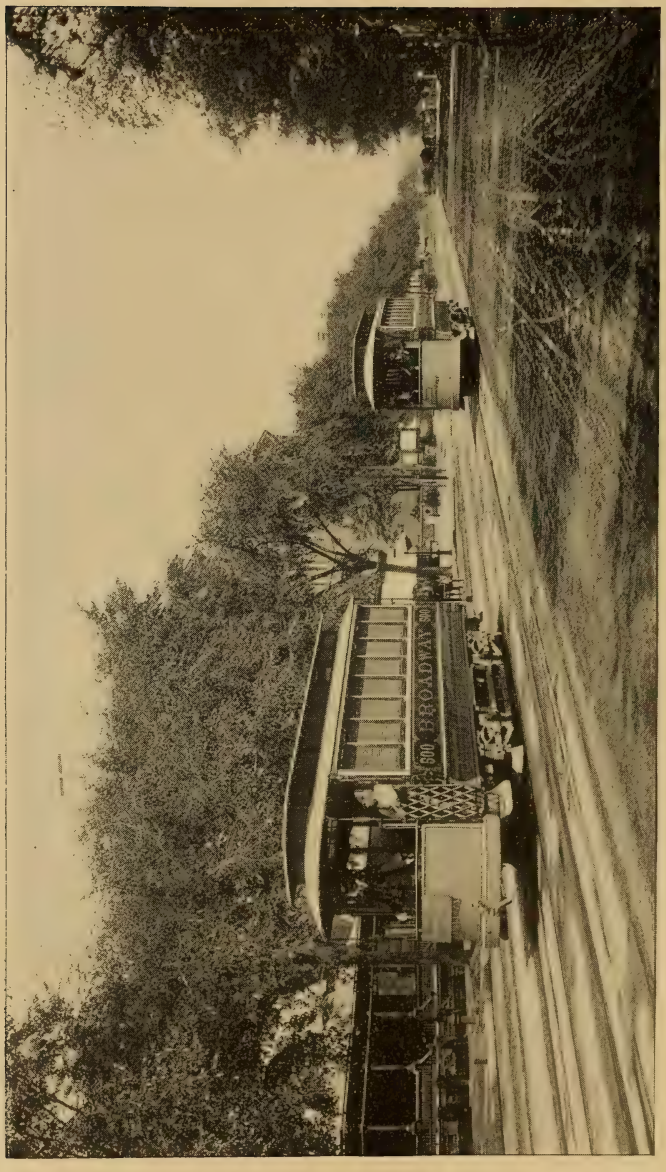
In general contour and character these first conduits did not essentially

differ from those which are in satisfactory operation to-day, but the designers did not realise the necessity for mechanical strength, and the early failures can be ascribed almost entirely to defects in this regard. The Boston conduit was constructed for the West End Street Railway Company, of Boston, one of the first roads to adopt electricity as a motive power, and the first large road to undertake the equipment of its lines for electric operation.

After about six months' operation, which was a series of almost daily failures and troubles, this conduit was abandoned and the officers of the company and the public at large were thoroughly convinced that it was impossible to build and operate an underground conduit road successfully. Inasmuch as the West End Street Railway Company was at that time the largest street railway system in the world, both in track mileage and number of cars in operation, the signal failure of the underground system effectually stopped all further progress in this direction, and the city authorities, recognising the great advantages of electric traction to the people, very wisely granted permission to construct overhead trolley lines throughout the city of Boston.

The pronounced success of the overhead trolley as a means of urban transit led to a rapid development of the system, the history of which has no parallel in the annals of mechanical and electrical engineering. When it is considered that the first underrunning trolley lines that could be regarded as commercial systems were built in the United States, at Montgomery, Ala., and at Richmond, Va., in 1887 and 1888, and that now every large city in the United States, with the exception of New York and Washington, is provided with extensive systems of overhead trolley lines; that these not only replace all the older horse lines, but, in most instances, double or treble their mileage; that the electric motor and generator, together with all the appliances that go to make up a successful system have been brought to the present high degree of perfection within the short period of about ten years, it is not strange that the capitalist, railway manager, and engineer have had no time to

SOME CROSS-OVER CONSTRUCTION



ALONG THE LENOX AVENUE UNDERGROUND CONDUIT ROAD IN NEW YORK CITY

study and develop other systems of electric traction.

Notwithstanding the great advantage of electric traction to the public, and its great value to a city in developing its suburbs, the authorities of New York City have persistently and stubbornly refused to consider any system of electric traction that contemplated the use of overhead wires. This objection to electric wires not only applied to trolley lines, but to all overhead wires. European cities will not tolerate poles in the streets, but in nearly all of them there are numerous overhead telegraph and telephone lines supported on the roofs of buildings. All systems of overhead wiring have been almost entirely done away with in New York, and considering the settled policy of the authorities in this regard, their refusal to permit overhead trolley fixtures in the streets was consistent.

This attitude of the authorities compelled the street railway companies of New York to seek for another system of traction, and it was evident to the officials of the companies that it would be useless to adopt or offer to the public any system of transit which would not be fully equal in all particulars to that of the overhead trolley. The fact that the street railways of New York City are controlled by enterprising and liberal-minded men has been very fortunate for the citizens of New York, as it required great courage to undertake the expenditure necessary to the solution of this problem in the manner finally adopted. It is, indeed, unlikely that the problem of underground electric traction would have been taken up again in the United States for many years and the money necessary to develop it expended, except through a large and powerful corporation such as is now in control of the New York street railways.

The history of cable road failures was much the same as that of the electric railways. In the first efforts to install a cable system in the city of Pittsburgh, on the first day of operation a car started from the car house to make a round trip, which should have occupied about an hour. It took that car almost one week to make the trip over the line, on account of certain mechanical weaknesses in the construction of the road. Notwithstanding this discouraging start, the building of cable roads went on until the admirable type now in use in New York City was finally developed.

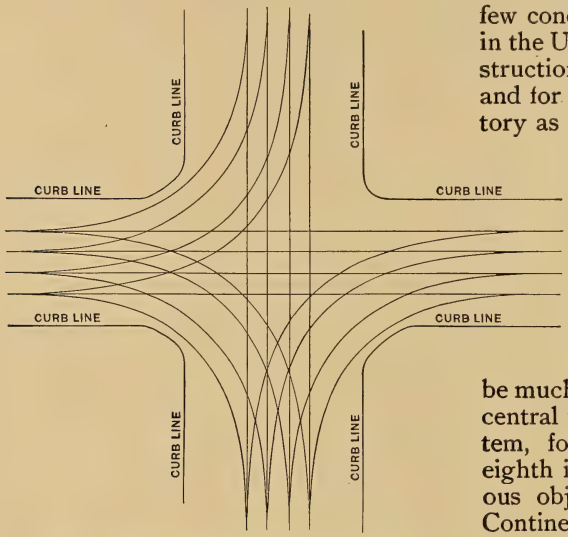
As perfection is a state of limited duration, the cable system cannot be expected to contravene the universal rule, and having for some time posed as unimprovable, it is now in its decline. Without laying claim to prophetic power, the writer considers it quite safe to say that the cable has been superseded, and that no more cable roads for city traction will be built, and that those now in operation will eventually be operated by some other power.

When it is considered that many roads have abandoned horse power for cable, and that cable was then abandoned in favour of electricity, it will be seen that the roads have been practically twice rebuilt, and all of this cost must somewhere find expression, either in the capitalisation or in the profit and loss account of the company. This cost, amounting to enormous sums, is never taken into consideration by those who are freest in criticism of street railway financial methods.

The growth of electric traction in the United Kingdom and in Europe generally has been slow compared with American development. The average American seems to have an inborn desire to be going somewhere and at as rapid a rate as possible: he must have the best means available for this purpose, even if it is not perfect and possesses many well-recognised disadvantages, and these demands have caused the rapid development of electric traction in the States.

The European, be he British, German, French, Spanish or Italian, does not possess that intense activity, so characteristic of the residents of the United States, Canada, Australia, and the other new countries. He appears to be more imbued with the spirit of art and beauty, and acts as if he thought that an improvement, to be of the greatest benefit to himself, his country or

city, should be developed slowly to assure perfection. If an improvement is effected in time for the use of the incoming generation it is all that one can expect. For these and various other reasons, the extension of the overhead trolley has been relatively slow in Europe, where, with plenty of time at



TRACK WORK AT A STREET INTERSECTION WHERE NO CONDUIT IS USED

command, engineers were at work perfecting the underground conduit.

At about the time of the failure of the Bentley-Knight system in Boston, a conduit road was constructed in Buda-Pesth, Hungary, by the Siemens-Halske Company, and as this construction was made in a very substantial manner, it is not strange that it proved an immediate success. The design of the particular conduit there used is open to objections, and its early operation was attended by many difficulties, which were corrected as they developed.

To-day the system in operation is substantially the same as that orginally constructed. About sixteen miles of this road were built, but the great cost deterred the company from making further extensions, and all the suburban lines were equipped with the overhead trolley. There were a few other attempts made in Great Britain and Europe to build and operate underground conduit roads, but none of them were successful until within the last few years, when some short lines were constructed at Brussels and Berlin.

The Buda-Pesth road is constructed with the slot adjacent to the tram rail, and not in the middle of the track, as is the custom with the cable roads and the few conduit roads that have been built in the United States. This type of construction is open to several objections, and for many reasons is not as satisfactory as the centre-slot construction, although it is cheaper to build, especially in European cities, where the street pavement is of a very substantial character.

The slot serves for the current collector or plough, and also forms the groove for the flange of the wheel. In consequence of this, the slot must be much wider than is the case with the central type. In the Buda-Pesth system, for instance, it is one and one-eighth inches wide. This is not a serious objection in Buda-Pesth or other Continental cities, as the wheel tires are all wide, and the narrow-tired light vehicle of the American type is practically unknown. But such a slot could not be used in an American city, as many wheels have tires not over seven-eighths of an inch wide, and some of the very light carriages have ¾-inch tires.

For this reason it was necessary to adopt in America a slot not over ¾-inch at the maximum, and this manifestly makes it impossible to use the same slot for the flange and the groove, inasmuch as the flanges of the wheels require a greater width than this. In the design and construction of special track work where there is a complication of switches, turn-outs, etc., the centre slot also is preferable, as the side slot gives rise to many complications in connection with the mechanical design of the work.

In the United States the centre slot has been adopted both for the cable and electric roads. After the completion of the Broadway cable system in New

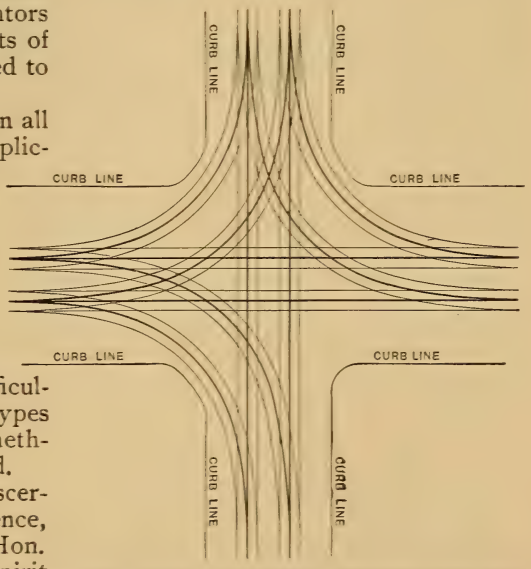
York, it was recognised that the enormous cost of the construction would prohibit the extension of the cable lines, and the directors of the Metropolitan Street Railway Company, in that city, cast about for some other system of mechanical traction, which would be fully as good as the overhead trolley, and, if possible, an improvement upon it.

During the years which had intervened between the early experiments of the underground system and the winter of 1892, there was more or less agitation in the press and otherwise against the overhead trolley wires, and it had come to be a settled conviction that if any other system of electric traction could be developed that could supplant the overhead trolley, it would be of great value to its inventor. This led to the development of an enormous number of systems, each one of which was declared by its inventor to be absolutely sure and certain in operation. As is generally the case in the development of any new art, the various inventors conceived and introduced all sorts of devices and complications supposed to add value to their invention.

In street railway operation, as in all other lines of mechanical work, simplicity is the greatest desideratum; but on account of the early failures, it was felt that a simple form of conduit was absolutely impracticable, and that some means must be devised to prevent leakage of current, and snow and mud accumulations in the conduit, and to overcome other supposed difficulties. To accomplish this, various types of switches and other complicated methods of construction were introduced.

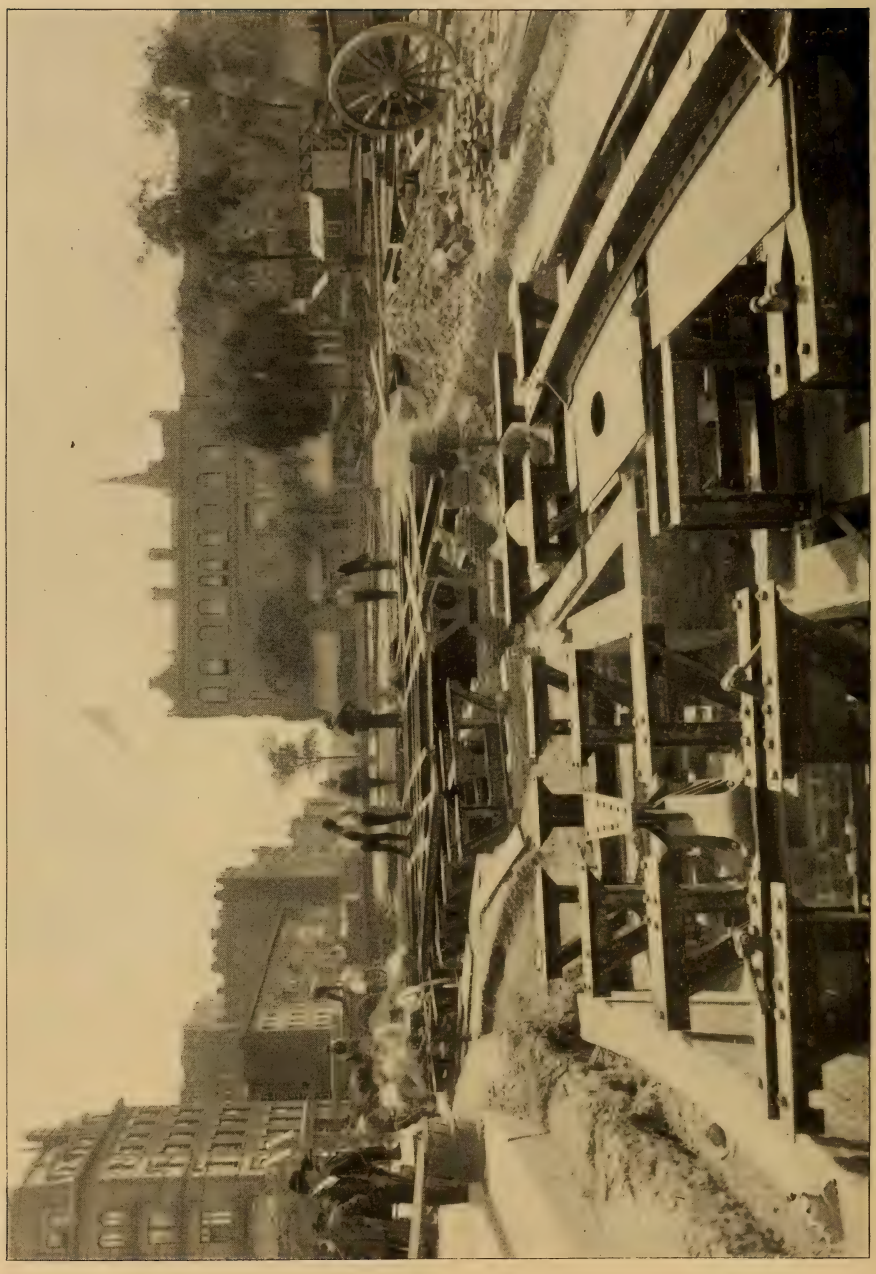
In the year 1892, in order to ascertain without prejudice or interference, the exact condition of the art, the Hon. William C. Whitney, the leading spirit in the Metropolitan Traction Company of New York, offered a reward of $50,000 for a system of mechanical traction applicable to the 189 miles of line then controlled by this company in the city of New York, and in order that a system, if one was found, should have the sanction of the State and the disposal of this munificent reward might be entirely free from prejudice, he requested the railroad commissioners of the State to undertake an investigation of the question and make the award. The board of railroad commissioners were advised that they had no power to determine the question, and the applicants for the reward then began to forward their inventions and devices to the company.

The avalanche of schemes which were precipitated upon Mr. Whitney and his associates was a matter of great astonishment to them, and it is probable that if they had realised how many impracticable inventors everywhere had been working on this scheme, they would have hesitated before making the offer. After an investigation of the best of the schemes proposed, it was clearly recognised that it would be necessary for the company, if it desired to secure a system which would be operative and satisfactory to the public, to undertake an investigation on its own account, and to carry on such experiments as might be necessary to develop a system.



TRACK WORK AT A STREET INTERSECTION WITH CONDUIT SLOTS

It was felt by the directors that the company could afford to spend a large



AN EXAMPLE OF CURVE CONSTRUCTION

sum of money in experimental work and in carefully considering all of the various systems, before actually deciding upon a means of transit which must be applicable to all its lines. If there had been only a few miles of lines to construct, the problem would have been much simpler, but the company was confronted with the question of the reconstruction of about two hundred miles of lines which were so interconnected that one system of traction must be used for a large proportion of the mileage. It would be impossible for the company to operate connecting lines with different systems of motive power, without entailing a transfer of passengers at all junction points. If any system installed proved to be unsatisfactory in any particular, it followed that it must be abandoned and all money expended on it lost.

Inasmuch as the overhead trolley had proven so great a success wherever used, the company was naturally bound to adopt a system of traction equal in all respects to that developed with the overhead trolley. It was decided to send the company's engineer to Buda-Pesth to thoroughly investigate the conduit system in operation there, as well as all systems of mechanical traction which were in operation in Europe.

A careful study was made of the Buda-Pesth system on the ground, and in connection with the examination of the conduit road, through the kindness of the Hungarian authorities, all the records of the weather bureau were placed at the disposal of the engineer. Through these it was possible to ascertain the climatic conditions of Buda-Pesth for a period extending over twenty years. The average rain and snow-fall for each day, the temperature four times in each twenty-four hours, the barometer records, and the annual rise and fall of the river Danube, which has a material effect upon the drainage of Buda-Pesth, were ascertained.

The city authorities of Buda-Pesth very kindly provided also a map giving the entire system of sewers in the city, with the size of the sewers in each street and their level below the street surface. This, in connection with the maps of the street railway and the information furnished by the street railway officials and other data which were obtained, enabled a very accurate comparison to be made between the climatic and drainage conditions of Buda-Pesth and New York.

Inasmuch as the Buda-Pesth system had operated satisfactorily for several years, it was evident that a similar one could be made to operate equally well in New York City unless there were some conditions of climate or drainage which would prove obstructive. A careful consideration of the recorded rain and snow-fall in New York over the same period of time, and the temperature variations, showed that the city of Buda-Pesth has the more severe winter climate and heavier snow-storms. The sewer system of New York was found to afford much better drainage than that of Buda-Pesth, as in the high-water time of the Danube there is great interference with the drainage system of that city.

After the investigation of the Buda-Pesth conduit, visits were made to the European cities where any form of mechanical traction was in operation, and the various systems of traction were examined. As the officials of the different railway companies using mechanical traction very kindly furnished detailed information, it was possible to ascertain the real facts in connection with the cost and operation of these roads. Among the systems examined were the Serpollet, hot water, compressed air, gas motor, storage battery, and steam locomotive. None of these systems were as satisfactory in operation as the Buda-Pesth electric road, and the report of the engineer upon his return to New York was entirely in favour of the underground conduit electric system.

At that time the Metropolitan Street Railway Company proposed to construct a cable line in the northern end of the city of New York, on Lenox avenue, a section about four and seven-eighths miles long, and it was decided to equip this line, as an experiment, with the underground conduit.

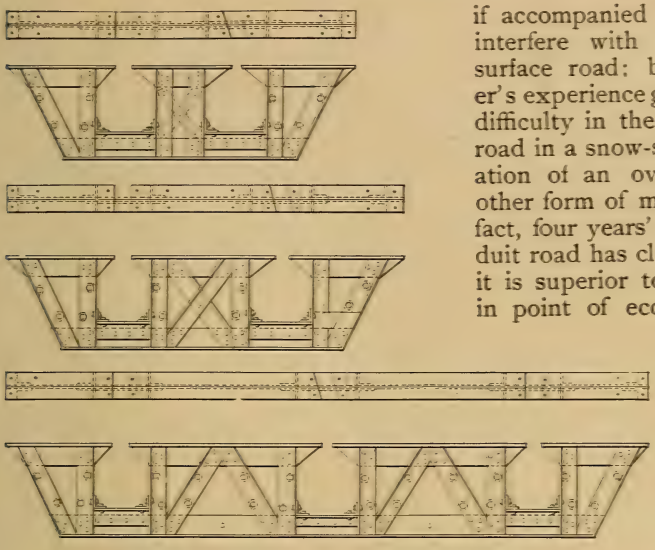
The General Electric Company, of

TYPICAL CONDUIT WORK AT A STREET INTERSECTION

New York, in which were merged the Bentley-Knight and many other electric manufacturing companies during the early development of electric traction, made a proposition to the company to electrically equip this road, allow the railway company to operate the system for twelve months, and, if at the end of that time, the operation proved unsatisfactory, to remove its apparatus and receive no compensation. A contract was made with the electric company on these lines, and the construction of the road was commenced in September, 1894. The first car was operated on April 1, 1895, and the road was officially inspected by the railroad commissioners in April, 1895.

Soon after it had been decided to install this underground electric system, and its construction had been commenced, the Metropolitan Street Railway Company of Washington, D. C., compelled, under their charter, to adopt some form of mechanical traction other than overhead trolley, investigated the plans of the New York company, adopted a similar type of construction, commencing work in March, 1895, and proceeded vigorously with the work of construction, operating the first car in the latter part of the following July.

These two roads, constructed and completed at about the same time, proved very successful from the start; in fact, the early operation of the Lenox avenue road was attended with much



MADE-UP YOKES AND STANDARD CROSS-OVER

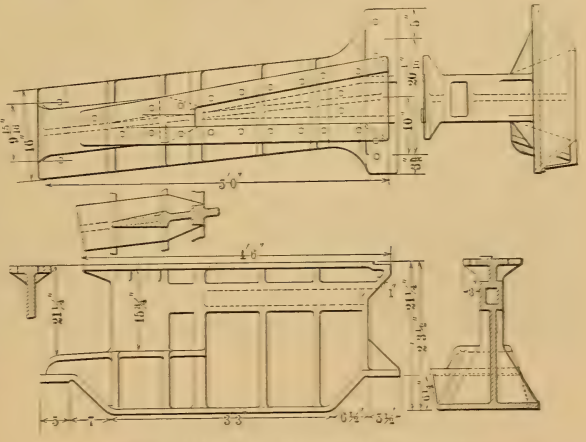
less difficulty and trouble than is usual with an overhead trolley road.

There were, of course, a number of troubles, chiefly due to mechanical faults which had to be corrected, but none of these were of any great importance. In the first two years of the operation of this road there was no serious interference with traffic from any mechanical or electrical cause although the road was in continuous operation twenty-four hours each day, Sundays included. There is but one case in the history of the road where the traffic was seriously interrupted, due to a heavy snow-storm. To the surprise of all connected with the road, the electrical leakage was practically *nil*, and the difficulties involved in its operation in snow-storms and bad weather were much less than had been feared.

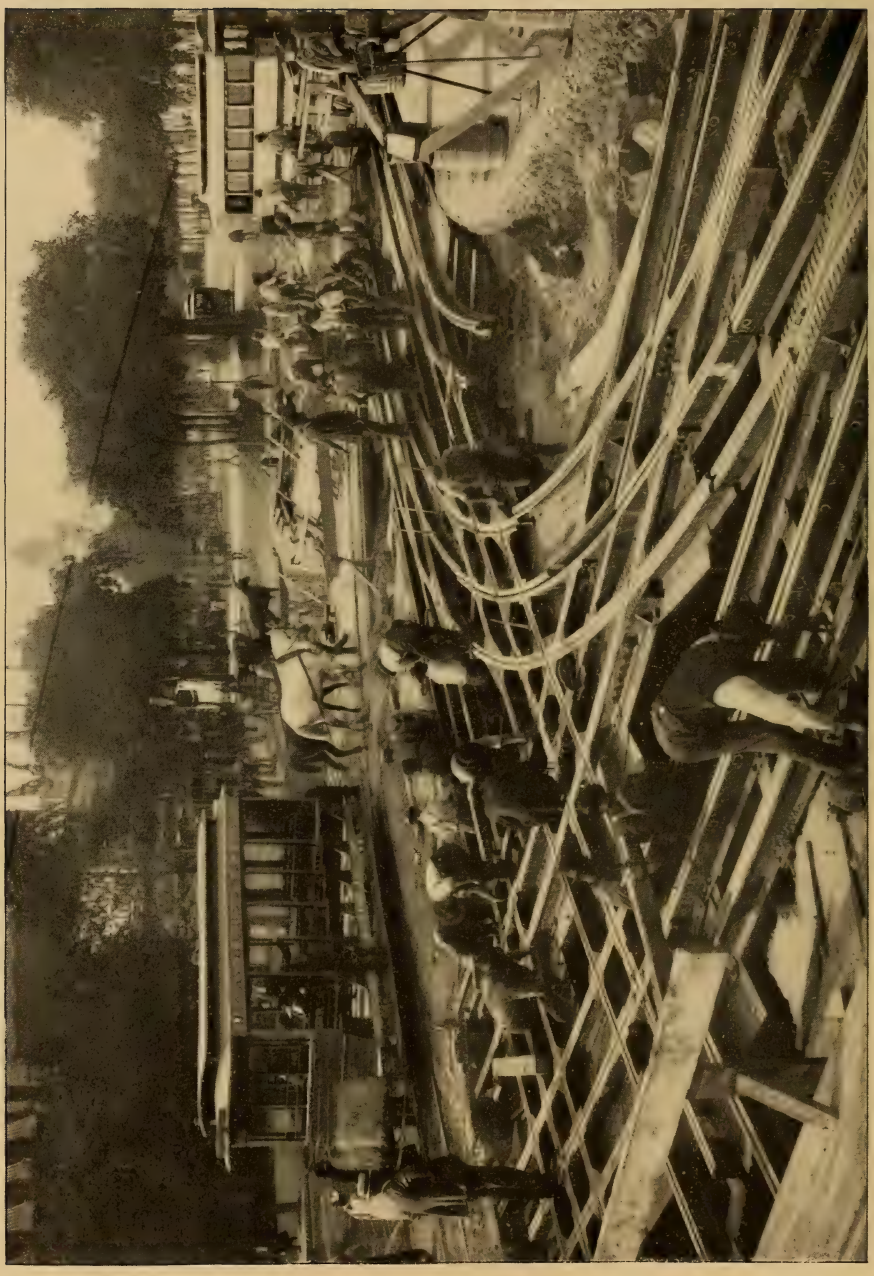
Of course, any mechanically operated road must be more or less interfered with by snow-storms, and it was not to be expected that the conduit road would be an exception to the rule. An enormous fall of snow, if accompanied by drifts, will seriously interfere with the operation of any surface road: but so far as the writer's experience goes, there is no greater difficulty in the operation of a conduit road in a snow-storm than in the operation of an overhead trolley or any other form of mechanical traction. In fact, four years' operation of this conduit road has clearly demonstrated that it is superior to the overhead trolley in point of economy and satisfactory operation, even in the northern climate of New York.

The development of the conduit system was due chiefly to the opposition of the public to overhead trolley wires on account of their unsightliness; but the system is superior in many respects to the overhead trolley, and, were it not for the great cost of construction, would, doubtless, extensively displace the latter system.

In any large overhead trolley system, it is necessary to observe the strictest supervision over the line construction and to maintain emergency crews on duty at all times to repair the lines in case of trouble or danger to the public. This is particularly necessary in winter weather. With an underground conduit, properly constructed, there is

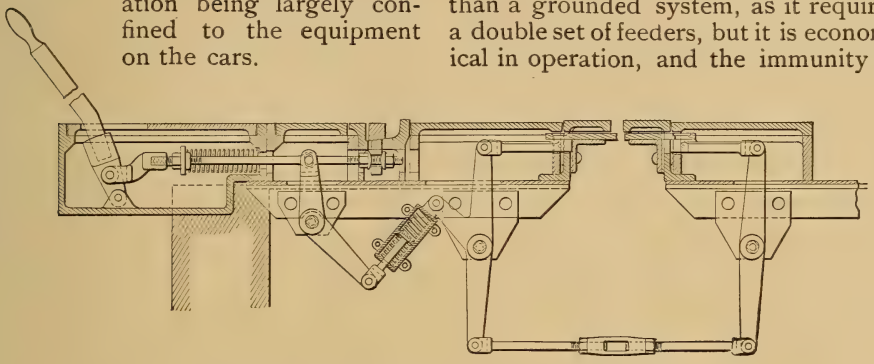


GUSSETT POST AT A TERMINAL CROSS-OVER



CONDUIT INTERSECTIONS AND TURN-OUT AT A STREET CORNER

nothing of this character to be feared, as all of the electrical conductors are underground and strongly supported, and it is practically impossible for any serious trouble to arise on the line, the troubles incident to operation being largely confined to the equipment on the cars.

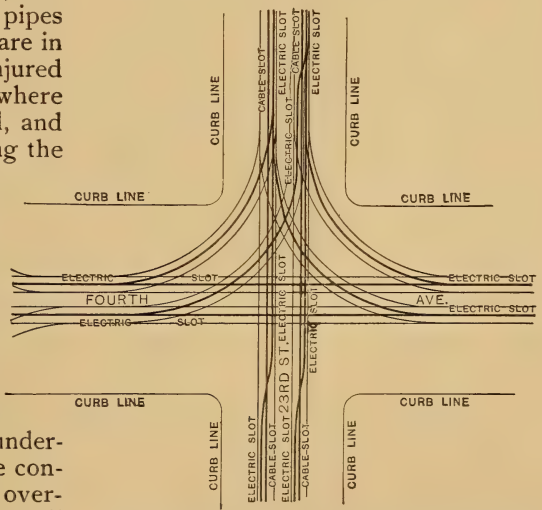


SWITCH MECHANISM FOR CROSS-OVERS AND TURN-OUTS

One of the greatest advantages of the underground conduit as compared with the overhead trolley, is the absolute prevention of electrolysis and consequent injury to gas and water pipes. This question of electrolysis in connection with the operation of overhead trolley lines is becoming very serious, and without doubt the water and gas pipes of most cities where such lines are in operation are being more or less injured from this cause. In many cities where the conditions are particularly bad, and the city officials are lax in guarding the general interests of the public, and where no great precautions have been taken by the railroad companies to prevent this trouble, enormous damage is being done.

There are very few cities in the United States to-day in which the pipes are not exposed to some danger by the return currents from the trolley cars. It would be possible to operate an underground conduit road with a single conductor, in the same manner as the overhead trolley is operated, using the rail and earth for the return circuit, but such operation gives rise to many difficulties which can be avoided and all danger from electrolysis obviated by the use of a system of double conductor bars and insulated return feeders. In this system both sides of the circuit are entirely insulated from the ground, and the current does not go into the ground at all. This type of construction costs considerably more than a grounded system, as it requires a double set of feeders, but it is economical in operation, and the immunity to the water and gas pipes is well worth the extra cost.

The chief objection urged against the underground conduit, so far as experience shows, is its great cost. This is inherent in the system, and it is impossible to properly construct and reduce the cost of construction much below that at present attained. It is a simple matter to build a track for an overhead



A STREET INTERSECTION WHERE BOTH ELECTRIC CONDUIT AND CABLE SLOTS ARE IN USE

trolley line or steam railroad operation, but when it becomes necessary to place a slot longitudinally in the street, with the edges overhanging their supports, which must be maintained under all conditions at a uniform width, the mechanical problems involved are greatly complicated.

The track construction of a conduit road is subjected to stresses entirely independent of those due to the weight of the cars, and in climates where the changes of temperature are rapid, abnormal strains are developed in the structure which must be provided for in its construction. It is a well-known fact that paving, especially granite and wood, expands and contracts under varying climatic conditions, and in an ordinary street whatever expansion there may be, must necessarily be taken up at the curb of the street or in the body of the pavement. With the slot in the street the tendency of the pavement is to expand in the direction of the slot, and the construction of a conduit road, whether it be for cable or electricity, must be sufficiently strong to resist this expansion,—otherwise the slot will be closed.

It is not an uncommon occurrence with the older cable roads to have the slot closed so much on a very cold night as to make it necessary to reline the slot in order to allow the grips to go through. This tendency of the slot to close must be guarded against in an electric conduit, and to provide for this a comparatively heavy yoke is absolutely necessary, and the design of the yoke must be such as to offer, with a given weight, a maximum resistance to slot closure. The shank of the plough used on the electric car is ⅜ inch thick, while the slot is ¾ inch wide, affording only 3-16 inch clearance between the slot rail and plough.

In addition to this strain, due to expansion of the pavement, there are other strains, induced through heavily loaded trucks passing over the slot rails. In many European cities there is a limit, fixed by law, for a load that can be carried on a four-wheel truck, and as the load increases, the width of the tire is increased under definite regulation. In American cities there is no limit whatever to the load that can be hauled on a truck other than the strength of the truck itself, and there is no law or regulation prescribing the width of tire for a given load. One would think, considering the great wear and tear on the pavements in the busy streets, municipal authorities would be alive to the importance of a regulation of this kind, as it would greatly increase the life of the pavements and save enormous amounts of money to the city in pavement repairs. This point, however, is entirely ignored by the authorities in the United States, and consequently a road must be so built as to withstand the maximum load that can be brought upon it.

The tram rails will support any load that can be rolled over them, as they are securely imbedded, on a solid foundation; but the slot rail, on account of the shape of the conduit, must overhang several inches; hence, with heavy rolling loads on the slot rail, excessive strains are induced in it and in the yokes, and unless of ample strength they are likely to break or deflect. For this reason it is necessary to use heavy and well-proportioned yokes, a very heavy slot rail, and to construct the work, so far as the concrete foundation is concerned, in a most substantial manner.

Various forms of underground conduits will probably be devised, differing from those now in use; but, judging from experience, it is not probable that any system of underground slotted conduits can be devised which will be materially cheaper than those now built.

The problem of underground conduit construction is greatly complicated by the question of special track work. By special track work is meant all the complicated pieces of track work where one line crosses another, or where it connects with another by means of curves and switches. In any large system of street railways there must necessarily be a great many such intersections, and in New York they are particularly numerous on account of the many lines crossing those running north and south.

At many of these crossings,—probably the majority of them,—the north and south lines connect by means of switches, in one and sometimes four ways, with the cross-town lines, all of which adds complication to the track work.

In the special track work required for overhead trolley lines the problem is comparatively simple, as it can all be supported on a solid base and securely fastened together. With the introduction of slots and underground conduits in one or more of the tracks, the complication is increased many fold, and if there are several slotted connections, the problem becomes one of great difficulty and the work is exceedingly expensive to construct.

The illustrations on pages 264 and 265 show the intersection, for instance, at two important New York streets. The first plan shows the character of the track work which would be required if there were no conduit, and the road were to be operated with the overhead trolley. The second view shows the work as actually designed and constructed with the slot, the heavy black lines indicating the slots. It will be observed that while the first plan is quite complicated, the second is very much worse.

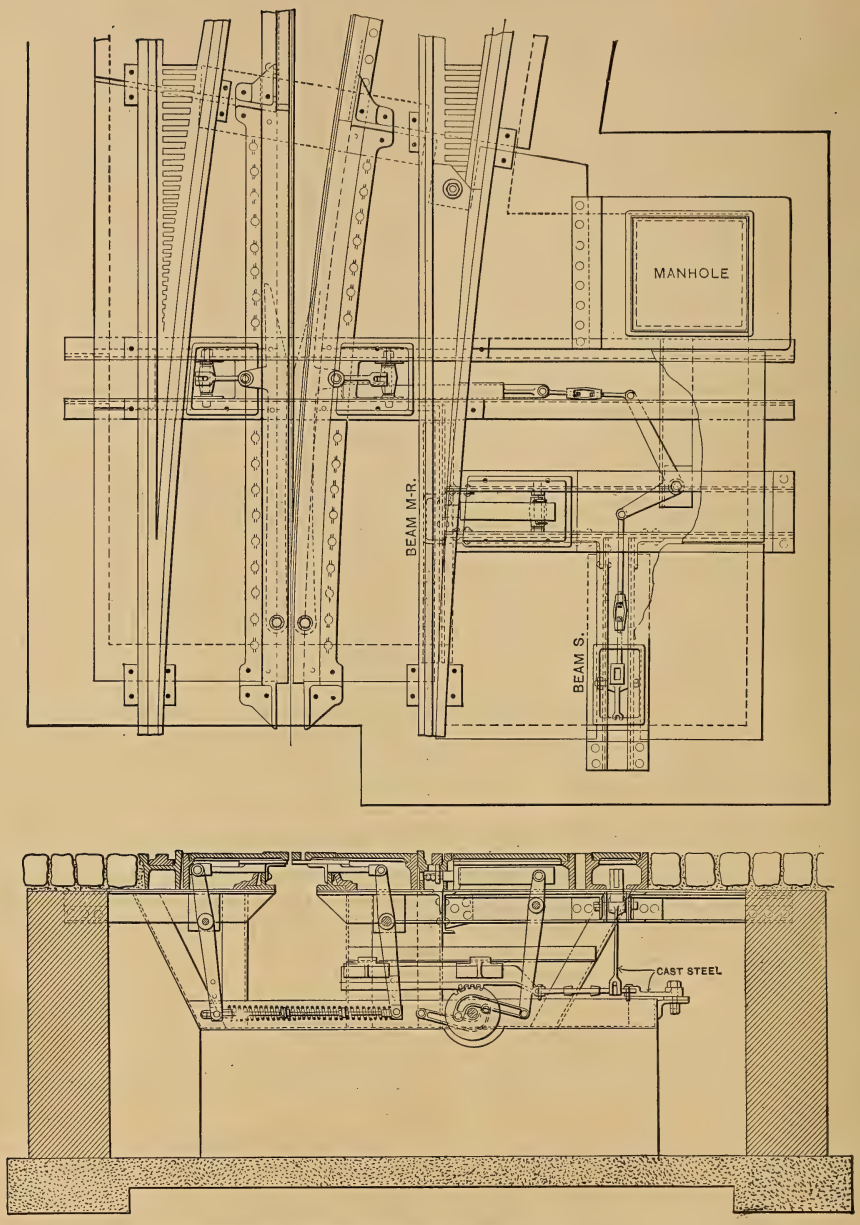
When it is remembered that under each of these slots, as shown by the black lines, the continuity of the conduit of the same form as in straight line must be preserved and the conductor bars conveying the electricity must be carried through, being terminated only at the intersection of the slots, and that all this surface, which is largely steel, must be properly supported from the foundations underneath by means of steel yokes, and in such a substantial manner that a heavily loaded truck, carrying from 40 to 60 tons on four wheels, can roll over it without injury to the work, it will be recognised, even by those unacquainted with mechanical engineering questions, that the design and construction of such work is a very difficult problem. The supporting of the various parts of the street surface in a manner which will keep it at a proper level, hold up the pavement and heavy trucks, maintain the slot at the proper width, and provide for contraction and expansion of the steel surface itself, requires great strength and exceedingly expensive construction.

The yokes for this special work must necessarily be of complicated design, as in many cases two conduits are close together, but not parallel with each other, and the yokes must be designed both for the conduits and also to support the steel and iron work forming the surface of the street. The illustrations on pages 261 and 269 show samples of special work in process of erection, and some of the complicated types of yokes which it is necessary to use with it.

The machinery required for the operation of the switches in conduit special work is also more complicated than with ordinary surface work, as it is evident that there must be two switches at each point, one to switch the car wheel, and the other to switch the electric plough in the slot in the proper direction. The mechanisms through which this is accomplished are shown by the illustrations on pages 271 and 274. The tram and slot switches are connected, by means of levers and bars, with a handle which can be operated from the street.

In some of the streets of New York, the problem is very much complicated by the fact that cable roads are in operation, and it was necessary to operate electric cars on the same street without interference with the cable operation. This necessitates a double slot, one being used for the cable grip and the other for the electric plough. The illustration on page 275 shows this double construction. A plan is also given on page 271 of the intersection at two of the streets where the electric and cable slots on one are crossed by the electric slot on the other, and these electric lines are joined by curves in two directions from one street to the other. These pieces of special work are probably as complicated as any piece of track construction that ever need be built, and are given to show the complications which arise in conduit construction.

Two of the illustrations on pages 276 and 277 show the construction used for



PLAN AND SECTION OF SWITCH MECHANISM AT A STANDARD TURN-OUT

crossing a steam railroad at grade, and the reconstruction of a highway bridge over a steam railroad where the headroom was limited and the conduit construction was necessarily confined to the same depth of structure as that of the original bridge.

The surface crossing is a steam railroad crossing of *T*-rail construction as ordinarily used, with a slot intersecting the steam railroad track, the structure being designed to carry the heaviest steam locomotives and freight trains over the slot and conduit.

In the second case the total depth allowable for the pavement and bridge

over the steam railroad was twenty-four inches. The headroom under the bridge could not be encroached upon, which necessitated the design shown in one of the illustrations on page 277. It will be noted that the conduit is included within the structure of the new bridge and that the total depth between the top of the pavement and the under side of the girders is about the minimum that would be allowed in any highway bridge.

Beneath each piece of special work vaults must be constructed, in order to have an easy means of access to switch mechanism, conductor-bars, and other electrical appliances. Access to these vaults is furnished through man-holes in the surface of the street. The foundations for the yokes supporting the special work are constructed in these vaults.

The latter are generally built of brick and concrete, and in all cases are connected by drains to the sewers.

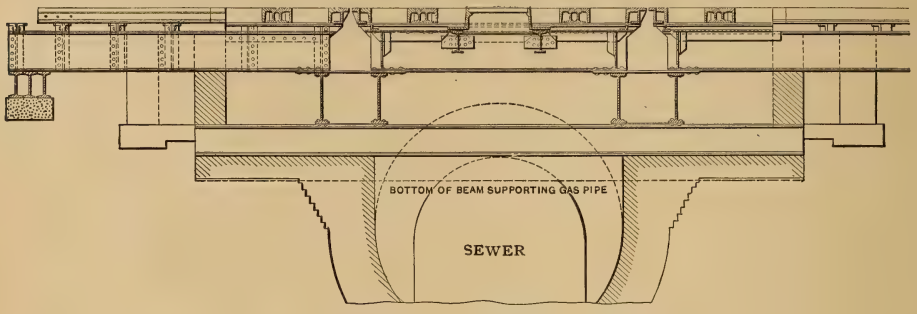
The maintenance of special work for overhead trolleys is expensive, but the introduction of the slot, if additional precautions are not taken, introduces a great element of weakness, and the wear on slotted work will be much in excess of that on surface work. This question of special work construction has been thoroughly worked out, and conduit and cable special work can at present be made which will wear as well as overhead trolley work; but the cost of this slotted special work in place will average at least five times as much as for the overhead surface construction.

Another great expense incurred in the construction of a conduit or cable road is that due to the removal of underground obstructions. In almost all cities of any size many pipes have been laid for water, gas and other purposes, and, as a rule, without any direction of the city authorities, and in such ways as the owners of the pipes might select. In cases where pipes are found to interfere with the laying of new pipes, the latter can be diverted from one side of the street to the other, or raised or lowered to accommodate the existing obstructions. In the construction of a conduit road, however, as the position of the tracks is fixed, underground obstructions must be removed to another position.

The illustration on page 278 shows a

A TRACK WITH A DOUBLE SLOT FOR ELECTRIC AND CABLE TRACTION

New York street corner, with the pipes so interwoven that, to construct the road, it was necessary to practically move every pipe shown. All these incidental expenses add enormously to the cost of the construction, and while it would be possible to build a good substantial conduit road cheaply in a new street or on a country road, the cost in a city is largely increased on account of the various obstructions encountered.



A CROSS SECTION AT A STEAM RAILROAD CROSSING

The question naturally arises as to the cost per mile of track of this slotted conduit construction. It is impossible to answer this question intelligently, as the cost depends upon so many local conditions. In New York, for instance, taking into account the new paving required, which in many cases covers the entire surface of the streets, the removal of pipes and the unusually great expense of the special work, the cost will average about one hundred thousand dollars (£20,000) per mile of single track, inclusive of feeders.

In many cities where there are few underground obstructions and very little special work, and where the paving taken up can be used again, the cost might be brought down to $50,000 or $60,000 (£10,000 or £12,000). In European cities from $50,000 to $70,000 (£10,000 to £14,000) per mile of single track, would probably cover the cost;—even with extensive special work on account of the superior character of the pavement and its foundation.

The mechanical and electrical questions involved in the construction and operation of the road will now be considered. One of the illustrations on the opposite page shows a section of street

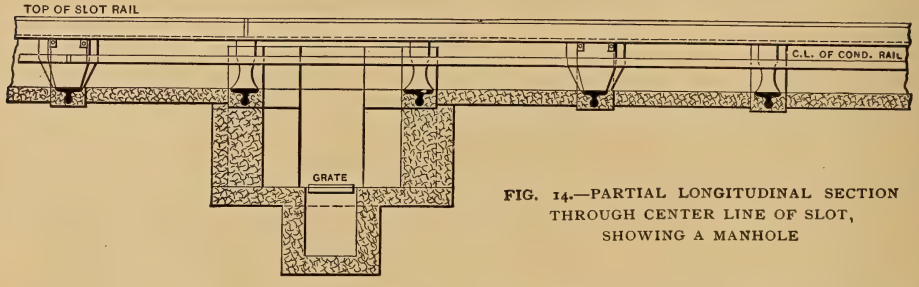


FIG. 14.—PARTIAL LONGITUDINAL SECTION THROUGH CENTER LINE OF SLOT, SHOWING A MANHOLE

with the construction as adopted in New York. The yokes are placed five feet apart, every third yoke being a so-called "box yoke," which is arranged for the reception of the insulators for the support of the conductor bars. These yokes are supported upon a concrete foundation.

In the construction, after the excavation is made, the yokes are deposited in the trench, and the rails are bolted to them. The rail is then adjusted to the proper lines and grade, and held in position by wooden blocking. The concrete is then tamped under the yoke in

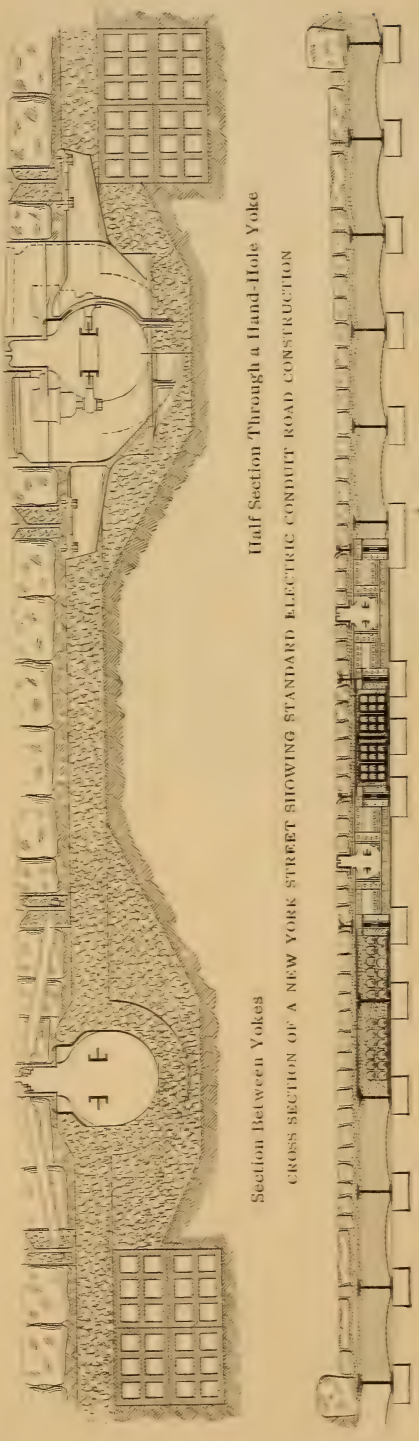
the same manner as gravel is tamped under a railway tie, and the entire track is brought to a solid bearing on the concrete.

The conduit itself is made of concrete, which is rammed against iron forms, which are temporarily placed in the yokes for that purpose. After the concrete has hardened, the iron forms are taken out, leaving a continuous tube of concrete for the conduit. The earth is then back-filled to within 15 inches of the surface of the street, and a layer of 6 inches of concrete is deposited the whole width of the track construction and two feet outside of the rails. This bed of concrete forms a substructure for the paving. In streets where asphalt paving is used, this subfoundation of concrete is brought up to within three inches of the surface for the asphalt paving.

The conductor bars are a combination of *T* and channel shape, this particular form being selected on account of its stiffness. They are supported from porcelain insulators, which, in turn, are bolted to the slot rail. To supply current to these conductor bars, feeders are placed in cement-lined iron or terra-cotta tubes, which are buried alongside of the track, as shown in both of the illustrations on this page. In laying these tubes a sufficient number are put down to provide for the present traffic and for the future growth so far as can be estimated.

These feeder tubes are connected with man-holes, about 400 feet apart, and in case of repairs to the feeders or in putting in new feeders, it is possible to draw them in and out without disturbing the paving, or the surface of the street, further than to take up the man-hole covers. The conduit proper is connected with cleaning man-holes at intervals of 200 feet. Each of these is connected to the sewer with a 6-inch drain pipe, and is provided for the double purpose of draining the conduit and for cleaning it of accumulations of mud.

This latter is a very important matter, as mud is constantly accumulating, and it is necessary to clean the conduit



Half Section Through a Hand-Hole Yoke

Section Between Yokes

CROSS SECTION OF A NEW YORK STREET SHOWING STANDARD ELECTRIC CONDUIT ROAD CONSTRUCTION

CROSS SECTION OF A BRIDGE CARRYING AN ELECTRIC RAILWAY CONDUIT

A NEW YORK STREET CORNER, SHOWING UNDERGROUND PIPE COMPLICATIONS

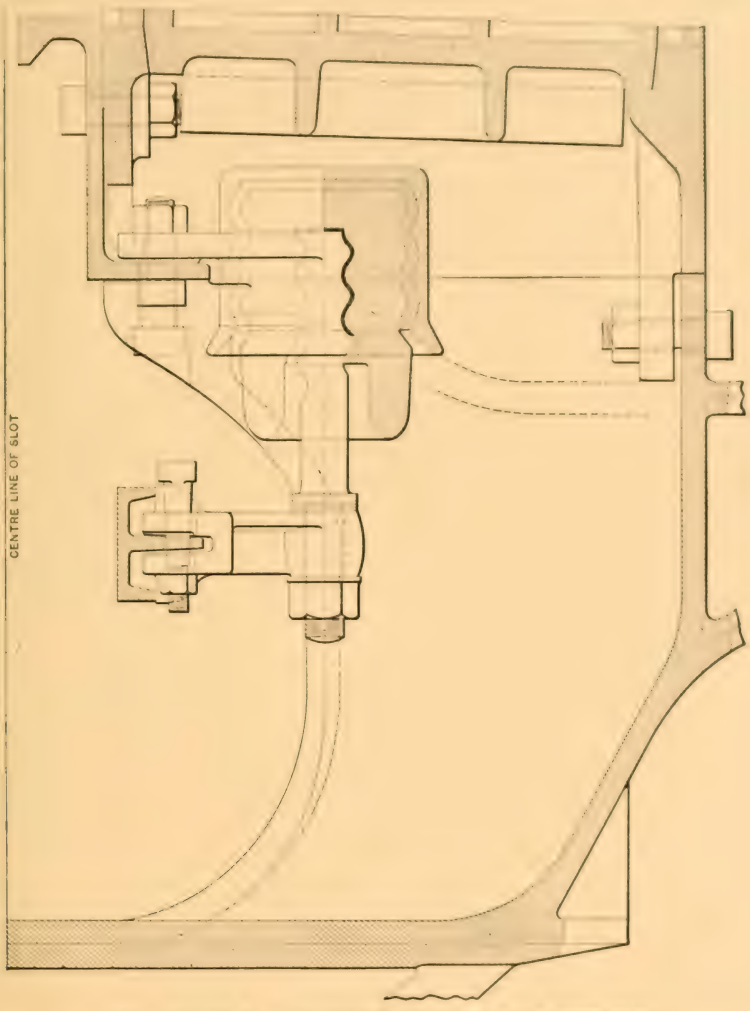
tube at least once a month in summer weather and oftener in the winter months to keep it in proper condition. The method of cleaning is to scrape the mud to the man-hole by means of a scraper, using men or horses to draw it through. A small electric cleaning car has also been developed, which is proving very successful in operation. The mud deposited in the man-holes is then taken out through the man-hole opening and carted away.

To facilitate the operation of the road, the conductor bars are divided into independent sections, separately fed directly from the power station. These sections are short, seldom over one mile in length. As there is no electrical connection between these various sections, and as the feeders, both outgoing and return, are provided with independent switches at the power station, it is possible to cut off the current from any particular section where trouble may occur, without interfering with the operation of the cars in any other portion of the city. On many sections where the traffic is heavy, very often four and sometimes six feeders are required to supply the current necessary for the large number of cars in operation. The diagram on page 280 shows the method of feeder distribution by which the conductor bars are thus fed with the current.

With this method of sectional current distribution, it is an easy matter, in case any trouble happens on one section of the line, to open the feeder switches connected with that particular section and cut the current out until the trouble is remedied, without interrupting the service on any other portion of the system. These feeders are also of great

use in starting up the cars in case of a sudden short circuit of such seriousness as to endanger the generators in the station. In such a case, automatic circuit breakers open, which instantly cut off the current from all sections of the road.

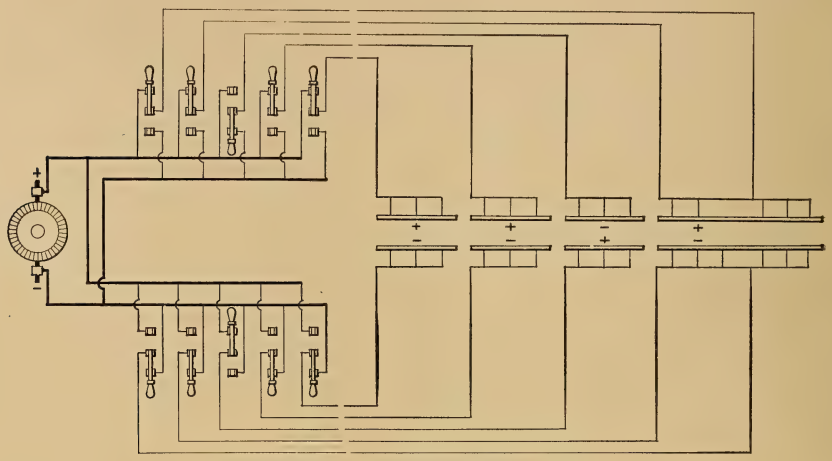
If there are a large number of cars on the line, several hundred, for instance, each motorman naturally tries to start as soon as the current is turned on, and the sudden demand for current to all these hundreds of cars is so great as to make it impossible for any ordinary power station to furnish it. With the sectional system of feeders, however, the electrical engineer in charge of the power station, in case of trouble, can open all of the feeder switches, and then throw them in, one after the other. In this way the cars on only one section are able to get the current, and these cars get under way before the next switch is closed. In a system operating a large number of cars this arrangement of feeder switches would be required for this reason alone, if for no other.



HALF-SECTION OF A NEW YORK CONDUIT AT AN INSULATOR

This sectional arrangement of feeders is of particular importance in connection with an underground conduit road,

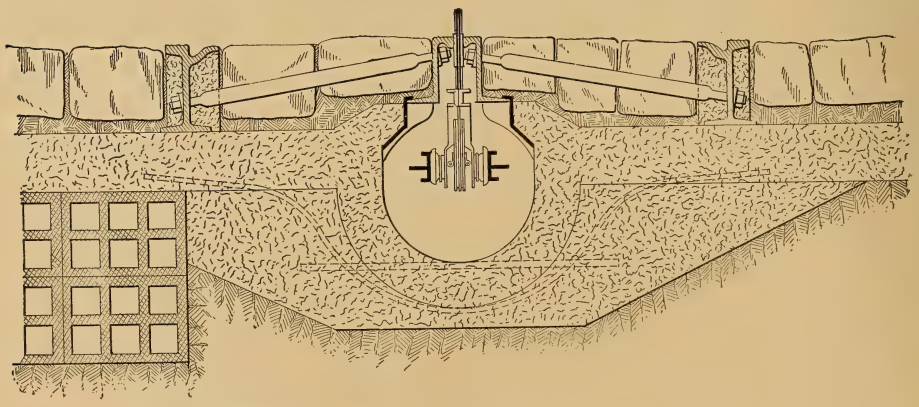
for a reason which does not obtain in overhead trolley operation. Inasmuch as both sides of the circuit on the conduit road are insulated from the ground, and the trouble of leakage of current, when it occurs, must arise on one side



THE METHOD OF FEEDER DISTRIBUTION

or the other of the circuit, this arrangement of the conductor bars and feeders in sections makes it possible to immediately correct temporarily any trouble from grounds, and thus renders interruption of car service impossible through the grounding of the conductor bars.

In any electric circuit, if a certain amount of current leaks to the ground at any point, it must at some other point return to the circuit, for it is a well-known law of electricity that the same volume of current which flows from the positive terminal of a generator must come back to the negative terminal, as the currents flowing at the terminals must at all times be identical in volume. It is evident that when through the breaking of an insulator, or from any other cause, contact with the ground is made on the positive side, there must be another contact developed on the negative side before current will leak to the ground.



A CONDUIT CROSS SECTION, SHOWING A CAR PLOUGH IN ITS WORKING POSITION

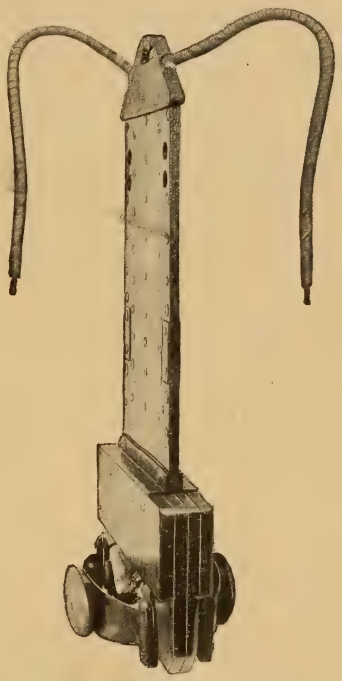
In a large system it is possible from various causes, mechanical and otherwise, to have grounds on the circuit, and as it is admittedly impossible to

absolutely prevent grounds, it is necessary to have some means of readily detecting them when they occur, and correcting the difficulty as soon as possible. With the positive and negative feeders connected to double-throw switches, one terminal of each switch being connected with the positive generator terminal and the other with the negative generator terminal, it is a simple matter to transfer one section of the conductor bar from the positive to the negative side of the circuit, or, what is the same thing, reverse the polarity of the two conductor bars in any section, by simply throwing the feeder switches from one terminal to the other.

If a ground occurs on a positive bar, for instance, in one section, no trouble will arise from this ground unless another occurs somewhere else in the city on the negative side, and there might be several points at which there would be grounds on the positive side in various parts of the system, without causing any material leakage to the ground or trouble in operation; but if a ground occurs on the positive side in one section of the city, and another should simultaneously occur on the negative side, perhaps miles distant from the positive ground, there might then be a serious loss of current to earth, possibly interrupting the service in the section affected.

In such cases, the engineer in charge of the station simply reverses the polarity of the bars in one of the grounded sections by throwing over the switches. By reversing the polarity of the positive side, this bar is made negative, and the flow of the current to the earth is thus immediately stopped, as both of the grounds are put on the same side of the circuit. It is thus that the only trouble which might cause serious interruption in the operation of the cars is guarded against. So far as the electrical equipment of the station and cars is concerned, the machinery is identical with that of an overhead trolley system. The only difference between the equipment of the cars used on the overhead trolley and that on the underground conduit is in the current collector. In the overhead trolley car, a trolley pole with a small brass wheel at the end is employed for taking the current from the wire. In the underground conduit the current collector, called a plough, is used for this purpose.

The illustration on this page shows one of the ploughs used in New York. The device consists of a steel shank, arranged for attachment to the truck of the car, carrying at its lower end two springs to which are attached cast iron



AN ELECTRIC CONDUIT CAR PLOUGH

shoes. These shoes bear on the conductor bars and take the current from the bar to the shoe. Connected to the shoes are rubber-covered wires leading up to the motor. The path of the current is from the conductor bars to the cast iron shoe, thence by rubber covered wires to the motor, and thence by the wire on the other side of the circuit to the negative shoe and to the negative conductor bar. While various forms of ploughs are in use, in different places, they much resemble one another in general design.

In the early history of conduit roads,

it was considered unsafe to use the standard voltage which had been adopted for overhead trolleys, namely, from 500 to 550 volts, and in Buda-Pesth a pressure of 350 volts was adopted and is still used. Inasmuch as the cost of the feeders increases very rapidly as the voltage decreases, it was considered highly important to use the standard voltage, if possible. With the introduction of the work in New York, 350 volts were adopted, as it was considered wiser to follow the Buda-Pesth practice, which had been demonstrated to be safe, than to embark upon an experiment. After operating for three or four months at 350 volts, however, it was found that there was no trouble from leakage or from grounds, and that 550 volts could be used with perfect satisfaction. Accordingly, the generators were rewound for the 550 volts and the system was operated at the standard voltage adopted for overhead trolley roads, since which time there has been no greater difficulty than with the lower voltage.

In conclusion, the writer would say, from the experience of the last three years, that the underground conduit road has all the advantages of the overhead trolley and in many ways is superior, both from the point of view of the company as regards the cost of operation, and from the public point of view as regards certainty of operation.

The only objection which can be urged against it is its great cost as compared with the trolley, but as an offset to this, no overhead wires or poles are necessary and there is nothing to detract from the appearance or beauty of the city. On account of the great cost, and the consequent burden of interest and sinking fund, the installation of the underground system would not be practicable except for lines with very heavy traffic and for companies operating under perpetual or long-term franchises. But, where conditions will allow its use, in the writer's opinion, it is superior to any other form of mechanical traction that has yet been developed.

ELECTRIC TRAMWAYS IN GREAT BRITAIN

By Robert W. Blackwell

ON THE DOVER TRAMWAYS

THE British inventor and investigator gave no small share of attention to the solution of the problems of electrical motive power in the earliest days of the art. The Giants' Causeway, Brighton, Blackpool, and Bessbrook-Newry tramway lines, operated, respectively, by Messrs. Traill, Magnus Volk, Holroyd Smith, and Mather & Platt, in 1883-4, were among the very first practical applications of electric motors to traction.

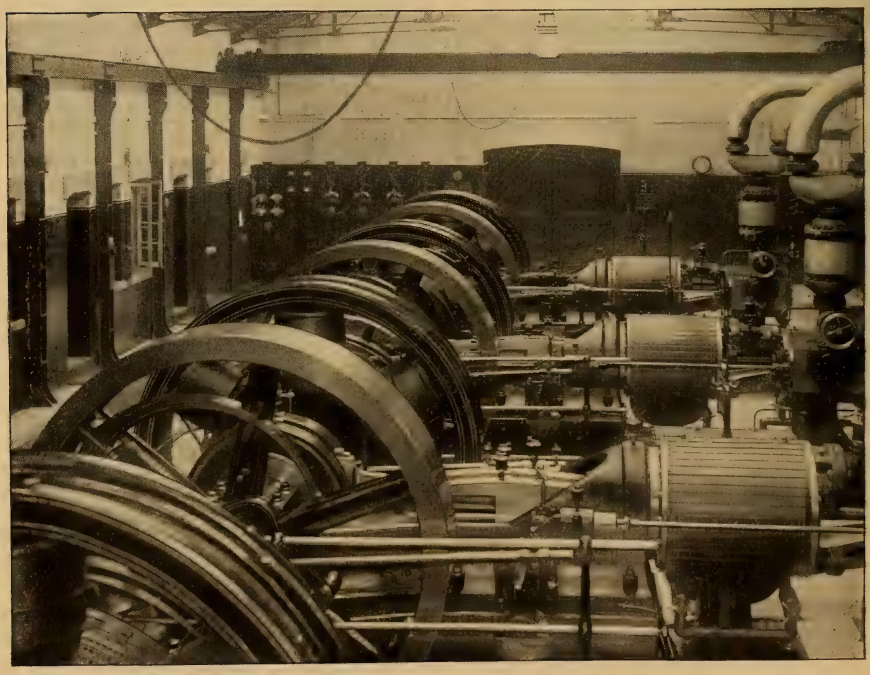
That they met with but little encouragement does not lessen the credit due to their efforts. The public at large did not then even approximately appreciate the value of tramways of any kind,—in fact, is but just beginning to estimate them at their true value,—and turned a cold shoulder to the proposers of any scheme looking toward their extension or improvement.

That this should be the case is scarcely cause for wonder. Even in the United States, where tramways had long been held in high esteem as an indispensable public convenience, and where the inefficiency of animal, steam and cable power was freely acknowledged, it required about six years of earnest effort and great expenditure by the original inventors and promoters before any appreciable effect was produced on the street-railway interest. Commercial success, however, being once an accomplished fact, the electric railway "boom" attained colossal proportions in the States, and the magnificent total of 41,000 cars operated over 15,000 miles of track, was attained within the short period of seven years.

It would, of course, be absurd to expect any such great or rapid result in Great Britain. Conditions widely differ, and the British promoter, owner, and manager have been, and are, forced to make haste slowly, and to cope with restrictions and difficulties from which America has been wholly free. Chief of these was the Tramways Act of 1870, which, among other things, enacted that at the end of a 21 years' term the local authorities of any city, town or district should have the option of purchasing tramways built and operated by any person or company on terms of payment which considered only the net value of the plant owned by the operator at the time of the forced purchase.

It would hardly be expected that, in the face of this provision, private enterprise could subscribe to schemes connected with a motive power about which so little was known. Telegraph and telephone engineers were, furthermore, very much alarmed at possible interference with their systems, and vague, but

CARS ON THE BRISTOL TRAMWAYS, SHOWING THE CHARACTERISTIC SIDE TROLLEYS



THE POWER STATION AT BRISTOL. MC-INTOSH & SEYMOUR ENGINES

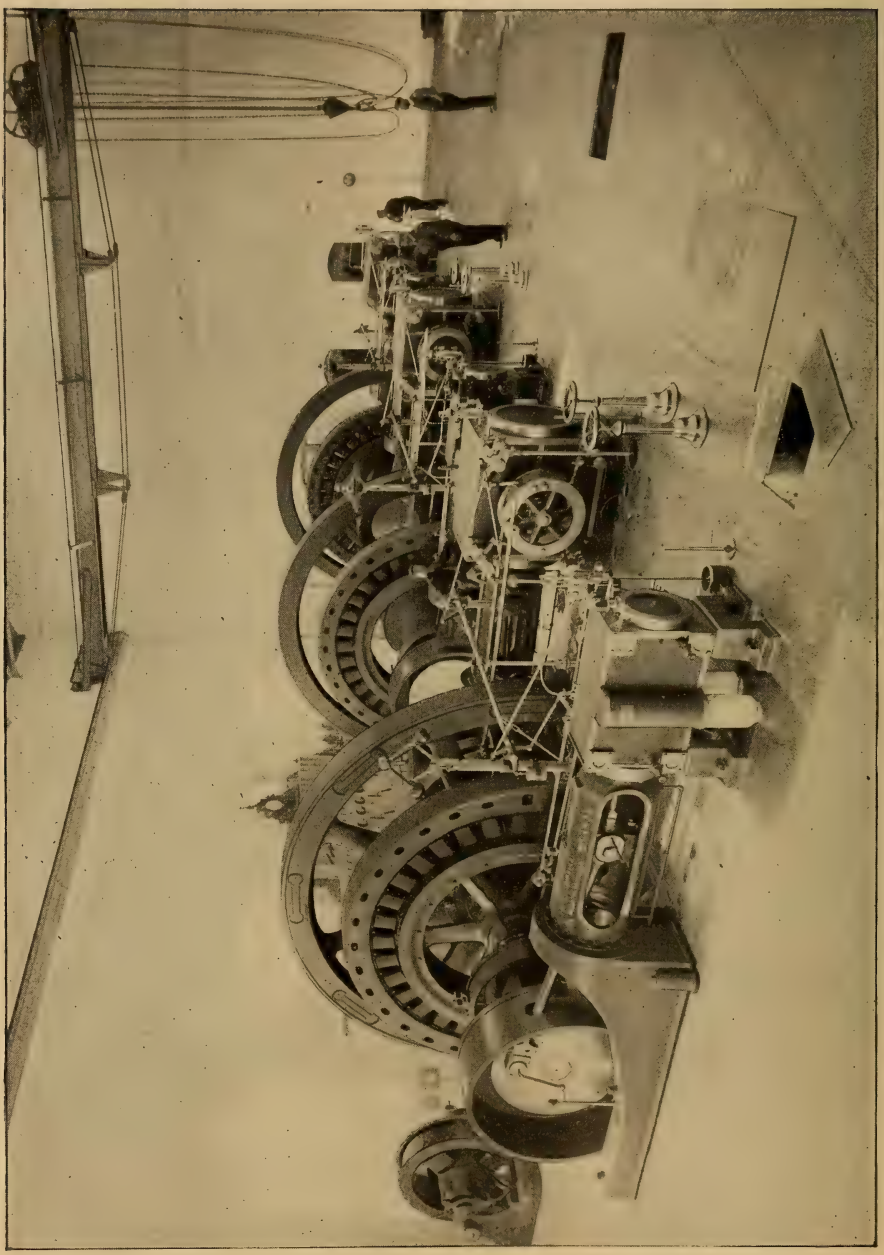
alarming, reports were received from America to the effect that great damage to gas and water pipes might be produced by electrolytic action. In consequence, the Board of Trade drew up stringent regulations, of which the most important was that the drop in voltage on the return circuit should not exceed 7 volts.

While these rules, with their later additions, are, undoubtedly, of substantial value, and serve their purpose in the protection of the public, they have naturally rendered impossible any but the best and most permanent construction, which means very heavy first costs. Furthermore, the great expense and delay of the legal procedure necessary to be pursued in securing franchises or extensions thereof, permits to substitute mechanical for animal power, or to obtain increased financial assistance, have always heavily handicapped tramway progress. The necessity of dealing separately with the several local authorities through which a proposed line may pass and the tendency toward municipalisation of all public services, which has so strongly manifested itself of late years, proved serious stumbling-blocks which all but barred the path to success.

Taking one consideration with another, it took much more than ordinary courage of conviction to attempt electric tramways in Great Britain on any considerable scale, and it is not surprising that only about 30 miles of track were electrically operated prior to 1895, this mileage being made up of a number of small and unimportant lines, fitted, to a great extent, with experimental and crude apparatus.

ANOTHER VIEW OF A BRISTOL CAR

It may be fairly said that little or nothing of practical value had been done in Great Britain until Mr. J. Clifton Robinson undertook an energetic crusade in favour of electric traction. Having enjoyed exceptional opportunities for expert investigation as the manager of successful tramway enterprises both



THE POWER STATION AT MIDDLESBROUGH. REYNOLDS-CORLISS ENGINES. EQUIPPED BY THE BRITISH THOMSON-HOUSTON COMPANY, LTD., LONDON

in Great Britain and America, he was in a position to intelligently consider and determine the question as to how far American results (then the only obtainable data of value) could be successfully adapted to conditions peculiar to the other side of the Atlantic. His able presentation of the claims of electric motive power to immediate consideration secured the support of Mr. George White, the manager and moving spirit of the Bristol Tramways and Carriage Company, Ltd., and of the Imperial Tramways Company, Ltd. (the latter controlling many important tramway

A CAR AT MIDDLESBROUGH

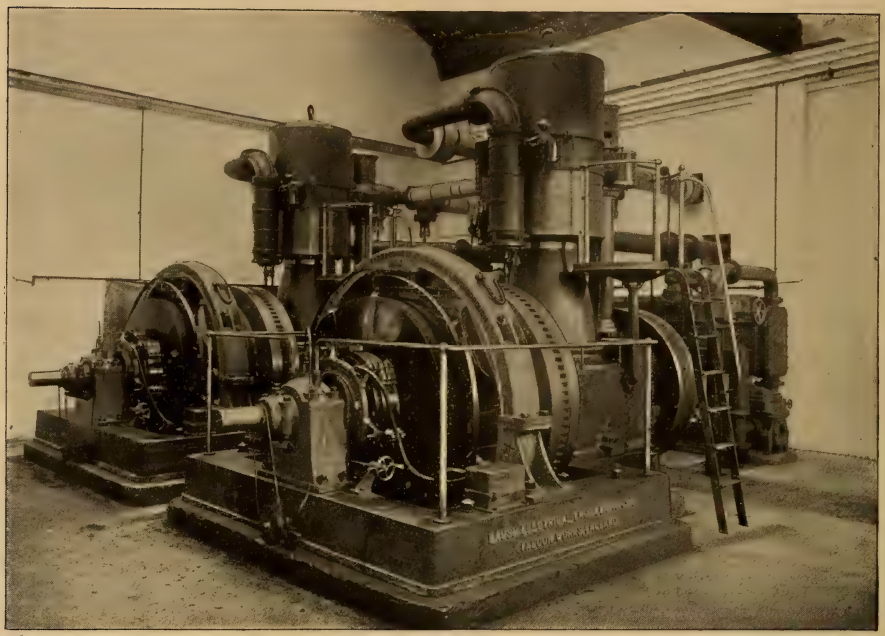
enterprises in England and Ireland), and of Mr. Samuel White, the secretary of the same companies.

Their united efforts bore immediate fruit in the electrical equipment of the Bristol and Dublin Southern Tramways, and of the Middlesborough line at a somewhat later date, all being model and highly efficient plants, no expense having been spared to secure the very best engineering results, both in design and apparatus, and the consequent highest possible economy in operating costs. Many other important tramway schemes, still pending, are controlled by the same energetic and intelligent management. The most prominent of these enterprises is the London United Tramways Company, which is to construct about 13 miles of electric lines in the suburbs of London.

The demonstrated success of the Bristol and Dublin lines, awakened a widespread interest in electric traction, with the result that up to October, 1898, about 150 miles of track were electrically operated, employing about 500 motor cars, while an approximately equal amount of rolling stock and mileage is under construction. These figures include all overhead and underground electric railways.

The Bristol plant consists of four direct-coupled, 150-kilowatt Thomson-Houston railway generators, running at 150 revolutions. Since the opening many additions have been made to the line, the latest extending about four miles away from the power house.

To come within Board of Trade rules, special feeder cables running to the rails and overhead line are connected to a "booster" in the power station, which can, if necessary, raise the voltage 100 volts on the overhead line and which

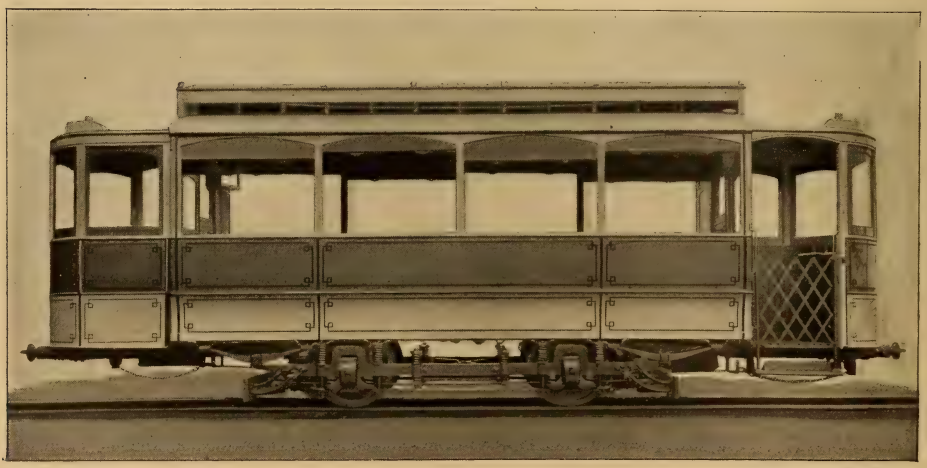


A GENERATING SET FOR THE KIDDERMINSTER & STOURPORT ELECTRIC TRAMWAY. BUILT BY THE BRUSH ELECTRICAL ENGINEERING CO., LTD.

reduces the drop of potential from 7 to 3 volts on the return circuit.

About eight route miles are now electrically worked, and it is proposed to immediately transform the remainder of the company's lines, in all about twenty-five route miles. A model power plant will be installed in the centre of the city. The entire work will be carried out under the immediate supervision of Mr. J. Clifton Robinson, Mr. Horace F. Parshall being the consulting engineer.

At Dublin, the "Southern" electric line, as originally equipped, ran south-



A CAR OF THE KIDDERMINSTER & STOURPORT ELECTRIC TRAMWAY. BUILT BY THE BRUSH ELECTRICAL ENGINEERING CO., LTD., LONDON

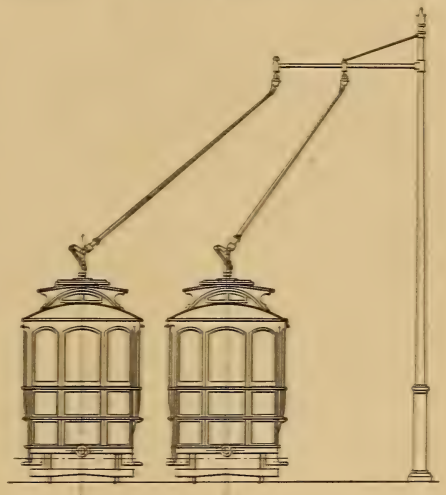
wards from Ballsbridge to Dalkey, a distance of eight miles. The design of the line is of exceptional interest, and marked a new departure in tramway work. For local reasons it was found necessary to have the power house at the Ballsbridge terminus. This having been decided, the problem that immediately presented itself was, under the conditions, to observe the Board of Trade regulations as regards drop of voltage in the return circuit. It was quite impossible to supply current at 500 volts from the power house, and, after careful consideration of the comparative merits of high-pressure direct current with transformers, and alternating current with motor generators, it was finally decided to use the latter, and to have two substations, one at the far end of the line, and the other at its centre. Direct current is supplied to the line from these substations, the plant in which consists of so-called motor generators, that is to say, synchronous alternating current motors, direct-coupled to direct-current generators. At the main power house alternating current is generated and supplied on the three-phase system.

After a comparatively short period of successful working, the "Southern" line was absorbed by the Dublin United Tramways Company, which now controls the entire service of the city.

Since this amalgamation, another line has been equipped and opened for traffic, extending northward from Clontarf to Dollymount. This line is supplied from a separate power house, in which direct current is generated. Both these lines have been running very successfully since the start. Large extensions are contemplated and are now under construction, and Dublin will ultimately have two hundred track miles of electric tramways.

To supply current for all these lines, the Dublin United Tramways Company is building a new central power station of about 20,000 H. P. capacity. This is destined to take the place of the existing plants, and will certainly be one of the finest stations in the world. At present six Thomson-Houston units of 500 kilowatts each are being put in. The engines are cross-compound vertical Reynolds-Corliss engines, designed to run at 90 revolutions. The system when completed will operate about 300 cars. At present 50 cars are in operation, and 150 more are under construction. The entire Dublin system is supervised by the secretary and manager, Mr. William Anderson. Mr. Horace F. Parshall is the consulting engineer.

The Middlesborough line is most interesting from many points of view. It is practically a light railway connecting a number of towns of considerable importance. Fifteen miles of track (nine



THE SIDE TROLLEYS OF THE KIDDERMINSTER & STOURPORT TRAMWAY

route miles) are operated by fifty large cars.

Owing to local conditions the power station could not be built at a central point. To meet the necessities of the case, the use of continuous current generators was discarded and three-phase machinery and rotary converters were adopted. The power station contains three 300-kilowatt, 2500-volt, three-phase Thomson-Houston machines, directly connected to cross compound Reynolds-Corliss engines running at 100 revolutions. At the one substation there are three rotary converters, and two rotary converters are in the main power house. These converters are

ONE OF THE CARS AT GUERNSEY. BUILT BY THE BRUSH ELECTRICAL ENGINEERING CO., LTD.

practically direct-current generators, as far as the armature windings are concerned, but have three collector rings added, into which the three-phase current from the generators is led. As at Bristol, the entire equipment has been installed under the direction of Mr. J. Clifton Robinson. Mr. Horace F. Parshall is the consulting engineer.

The Coventry Tramway now operates six route miles by ten motor cars. A five-mile extension is now under construction and will shortly be opened for traffic. The design, construction and operation of the line have been controlled by Mr. I. Everson Winslow, Chief Engineer to the New General Traction Company, Ltd.

The latter company has also installed the Douglas Southern Electric line in the Isle of Man, operating three and one-half route miles and eight cars, the equipment being similar to that of Coventry. They have also under construction the Norwich plant, which is to be much more extensive than their other

lines. Norwich will shortly have nineteen route miles in working order, which will employ forty motor cars. The electrical equipment is to be Westinghouse. At Coventry and Norwich, copper bonds have been discarded in favour of Falk cast-welded joints, these being the first plants in Great Britain to adopt this system.

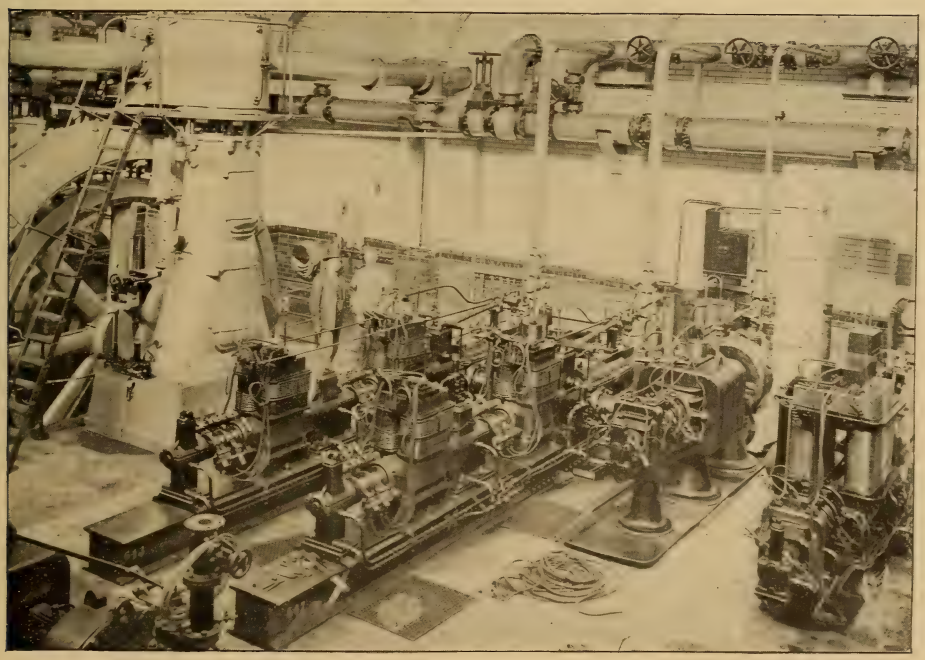
Under the auspices of the British Electric Traction Company, Ltd., Mr. Emile Garcké, Managing Director, and Mr. Stephen Sellou, Engineer, the Kidderminster and Stourport electric line has lately been opened. This line consists of about five miles of track, and operates eight cars.

The same company has under construction the North Staffordshire Electric Tramways (seven route miles and twenty cars), the Dudley and Stourbridge line (five route miles and nine cars), and the Oldham, Ashton and Hyde line (eight route miles and eighteen cars).

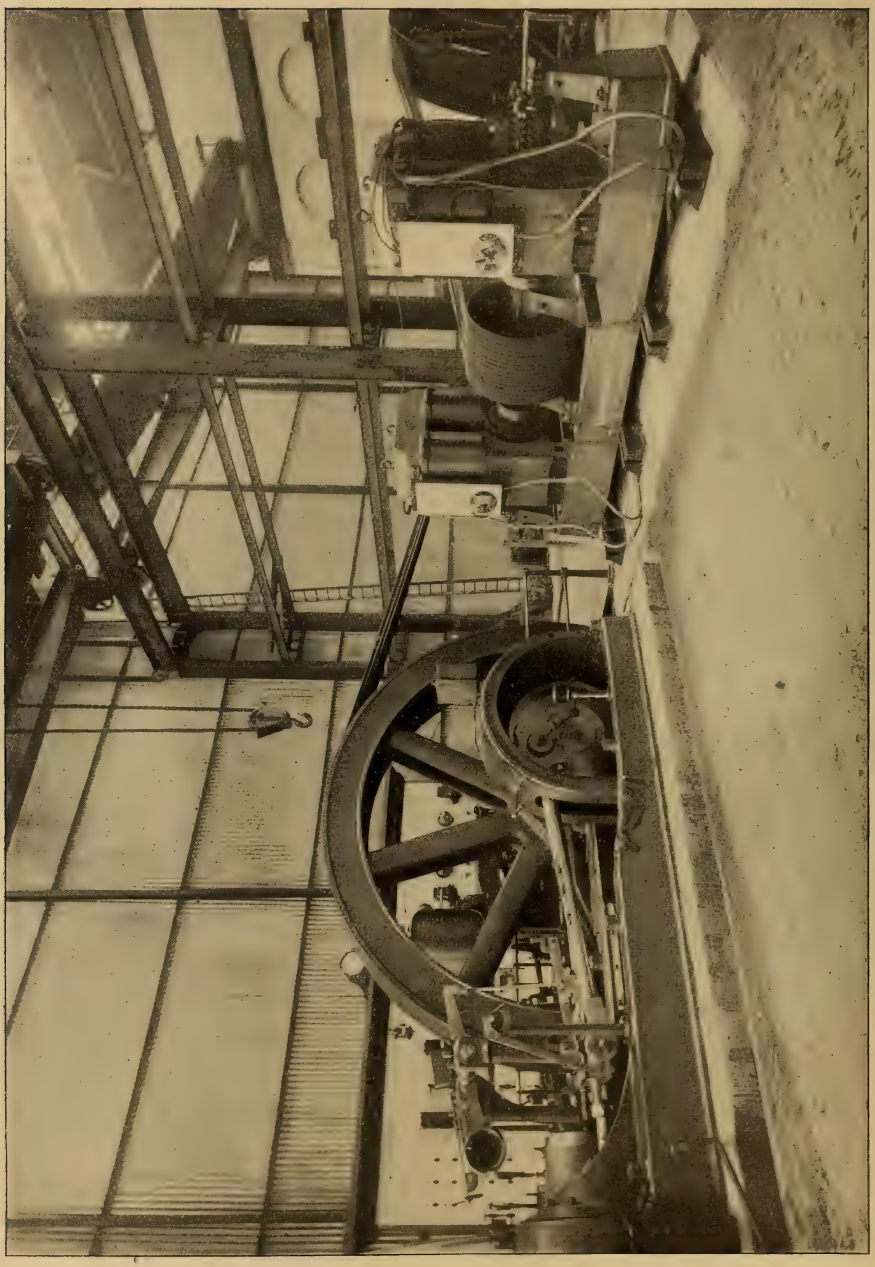
The "Potteries Extension" (twelve and one-half route miles) and the West Hartlepool (two route miles) lines, too, are under the same company's care.

The Blackpool and Fleetwood Electric Tramroad, having eight miles of double track and twenty-four motor cars, is a light railway. The power plant is located two miles from one end of the line. "Boosters" are employed to equalise the pressure, and two accumulator stations are located near the termini. The batteries are usually worked in parallel with the trolley line, supplying current to meet the sudden calls for power inseparable from traction work. They are also employed to take the whole load during early and late hours. The principal contractors for this road, Messrs. Mather & Platt, Ltd., of Manchester, have also constructed three electric tramways in the Isle of Man, having, in all, twenty-two miles of double track and operating twenty-eight cars. In these plants they have made extensive use of accumulators to steady the load and supplement the generating plant.

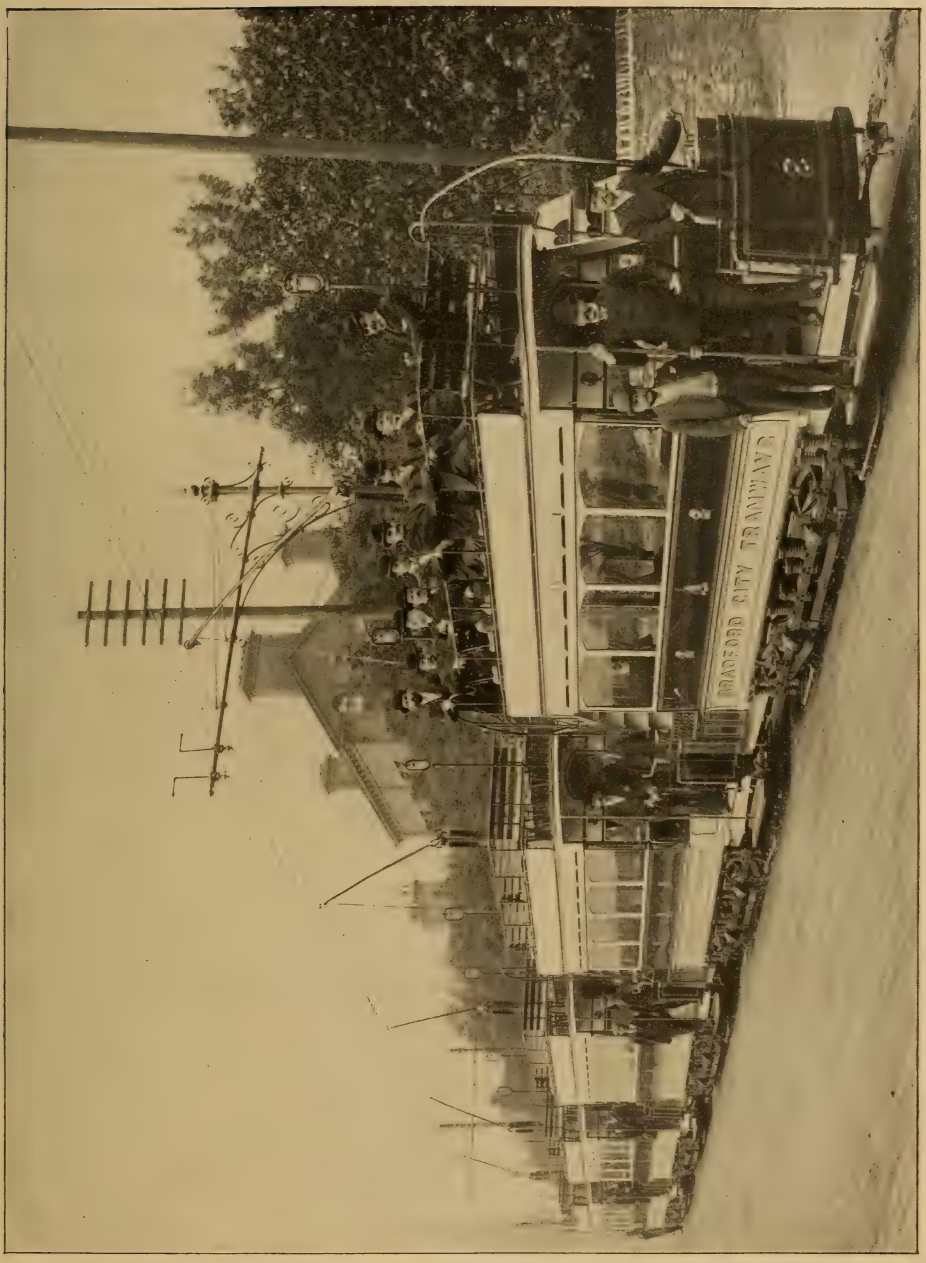
The electric tramway at Cork is the



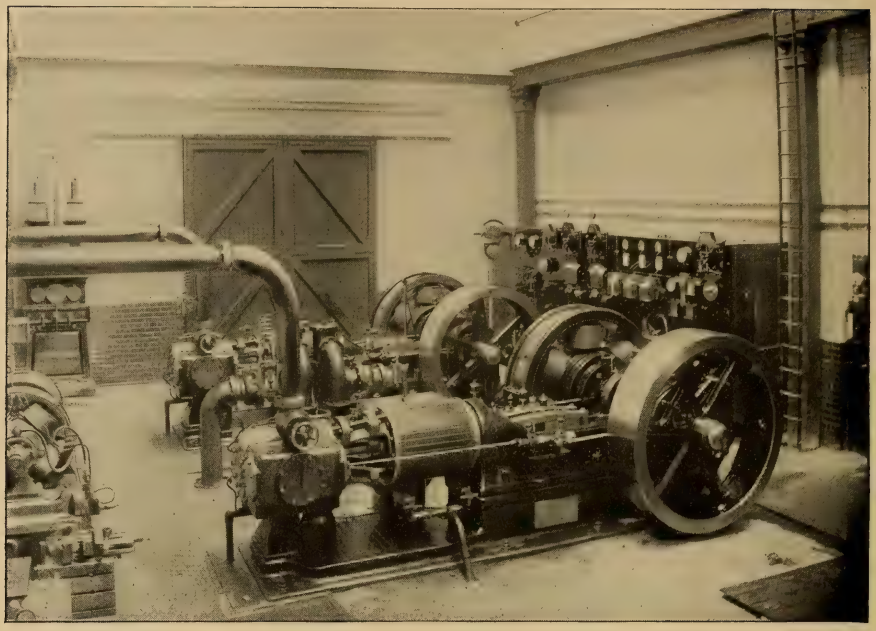
IN THE POWER HOUSE OF THE BLACKPOOL ELECTRIC RAILWAY. GENERATORS DRIVEN BY PARSONS STEAM TURBINES



THE POWER HOUSE OF THE LEEDS TRAMWAYS



BRADFORD CITY TRAMWAY CARS



THE POWER HOUSE AT DOVER. MESSRS. DICK, KERR & CO., LTD., LONDON, CONTRACTORS

CARS ON THE DOVER TRAMWAYS

latest one opened to traffic. It is a new line in every respect. Eleven route miles and eighteen cars are operated. The power plant consists of 200-kilowatt Thomson-Houston generators, direct-coupled to centre crank tandem compound condensing engines. It is a combined lighting and traction system, and a booster, a battery of accumulators, and a motor generator are employed to regulate the current and balance the current as used for the two services.

DOUBLE TRACK THROUGH THE MARKET PLACE AT DOVER, SHOWING SIDE AND CENTRE TRAMWAY POLES

The entire scheme has been developed by Mr. William Murphy, of Dublin, Mr. Horace F. Parshall being consulting engineer. Mr. Murphy has also in hand the construction of a light electric railway between Margate and Ramsgate, which will be about eleven miles long.

The Guernsey Electric Railway was equipped in 1891-2, and operates three and one-half route miles and eight motor cars. It is partially constructed as a tramway running through paved streets and partially as a light railway running over its own property. Very considerable improvements have lately been made in its equipment, and, under its present energetic management, it is probable that a very considerable electric tramway mileage will be shortly under construction in the Channel Islands.

The South Staffordshire line, covering eight route miles, with sixteen motor cars, was opened in 1893, and the Hartlepool line, with two and one-half route miles and eight motor cars, was given over to service in 1896. The Birmingham Accumulator line has three route miles and ten motor cars.

In the foregoing the writer has mentioned only lines developed by private

enterprise. Among roads, which are owned and operated by the corporations themselves, that at Leeds was the first one to be opened for traffic. This was in August, 1897. It now operates twenty-five motor cars and seven miles of double-track line. The permanent way was laid and the buildings were erected by the corporation engineers, the late Dr. John Hopkinson, F. R. S., acting as consulting engineer. The contracts for practically the entire plant were placed with local concerns of high standing in the community. The corporation has already decided to greatly extend the existing system, and has placed orders for fifty motor cars and an additional eight miles of overhead construction.

Dover followed shortly in the path of Leeds, placing thirteen motor cars and three and one-half miles of line at the disposal of the public in September, 1897. Halifax opened a three and one-half-mile line, with ten motor cars, in August, 1898, the entire contract being executed by the Electric Construction Company.

Bradford is one of the very few corporations which originally built its own tramways, granting the operating rights at first to private companies. The tramways committee, however, later decided that certain much-needed extensions of the existing service should be electrically equipped and worked by the corporation. The result to date is the five and one-half miles of line which were fully opened in August, 1898. There are twenty-four motor cars in service. Power is supplied the line from the lighting station already owned by the corporation, equipped with Willans engines and Siemens generators.

SOME OVERHEAD WORKS AT LEEDS, ENGLAND, INSTALLED BY MESSRS. GREENWOOD & BATLEY, LTD., LEEDS

A COMBINATION VESTIBULE BOGIE CAR ON THE GLASGOW CORPORATION TRAMWAYS

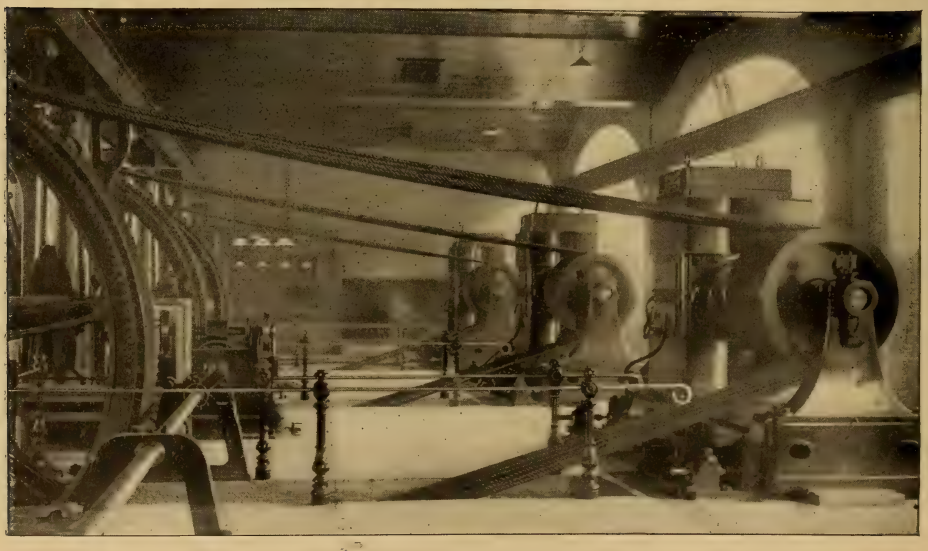
A ROOF-SEAT CAR ON THE GLASGOW TRAMWAYS

The opening of the Springburn section of the Glasgow Corporation Tramways was the first step toward furnishing the great metropolis of the North with a complete and modern system of rapid transit. The present line consists of two and one-half miles of double track and twenty-five motor cars. The power station contains three McIntosh & Seymour engines, direct coupled to 200-

A VIEW ON THE LIVERPOOL OVERHEAD RAILWAY, SHOWING THE ELECTRIC CONDUCTORS

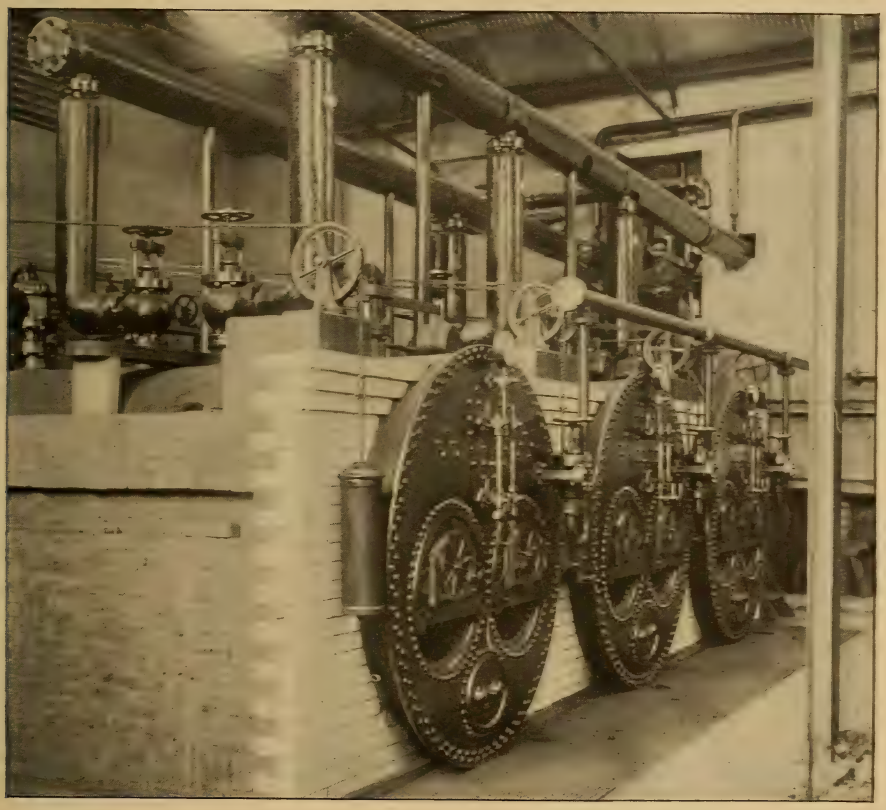
kilowatt Westinghouse generators. The cars and trucks are of several patterns, the two-compartment cars with central vestibule and bogie trucks being especially noticeable. The latter are the design of the general manager, and were built in the corporation shops.

Liverpool has also put into operation its first electric tramway, having equipped three miles of double track. The present power plant, as designed by the late consulting engineer to the city, Dr. John Hopkinson, F. R. S., consists of three direct-coupled Willans-Siemens sets, 300 horse-power engines and shunt wound dynamos, located in



THE ELECTRIC GENERATOR ROOM FOR THE LIVERPOOL OVERHEAD ROAD

the municipality's lighting station. Working in parallel with the dynamos is a large battery of accumulators, which can give 1000 ampères for five minutes, if required. An interesting feature is the employment of a booster, which, on one side, boosts up the feeder current, and, on the other, prevents too great a drop in the return circuits. The plant feeds the line at its two extremes, nearest and furthest from the power house. About thirty motor cars have been put into service, but it will probably be some little time before the tramways committee arrive at a full decision as to the electrical apparatus which will be best adapted to the complete undertaking proposed.



THE BOILER HOUSE OF THE DOUGLAS & LAXEY COAST ELECTRIC TRAMWAY, EQUIPPED BY MESSRS. MATHER & PLATT, LTD., MANCHESTER

The road at Blackburn comprises three route miles and eight motor cars, and sixteen trailer cars. Power is supplied by two sets of Belliss engines. The town of Hull is about to electrically equip a little over nine and one-half miles of double track and about half a mile of single track. The generating station contains three sets, consisting of Belliss engines of 470 I. H. P. coupled direct to Siemens' bipolar dynamos. A surface condensing plant, with electrically driven air and circulating pumps, is also provided. There are to be fifteen motor cars.

At Plymouth a power plant is to be placed in the local electric lighting station, and will be composed of two 100 kilowatt Westinghouse generators. The length of route is about two miles. Five motor cars will be operated. Sheffield, St. Helen's and Bolton are all under con-

A MOTOR TRUCK FOR THE WATERLOO & CITY RAILWAY, LONDON, EQUIPPED BY MESSRS. SIEMENS BROS. & CO., LTD., LONDON

tract for equipment, which will aggregate about one hundred motor cars and forty miles of route.

The City and South London Electric Railway was the first underground line to utilise electricity as a motive power. It is three miles long, double track. The original intention was to operate by cable, but a proposal put forward by Messrs. Mather & Platt, Ltd., for electrical equipment and working was finally accepted. The original plant consisted of three Edison-Hopkinson dynamos, 450 volts, 500 ampères, belt-driven from vertical compound engines, and fourteen electric locomotives weighing 10 tons each. It is a third-rail system. The line was opened to the public in December, 1890. The total equipment was from the designs of Dr. Edward

Hopkinson. The present equipment comprises sixteen locomotives, and another unit has been added to the power plant. A considerable extension of the company's system of tunnels is now under way.

The Liverpool Overhead Railway was opened in March, 1893. It is the only elevated line in the United Kingdom and on the Continent. It operates six and one-half miles of double track and has forty-four motor cars.

The Waterloo and City Railway, the second London underground line to adopt electric traction, was opened for the public in July, 1898. It is a third-rail system, a mile and a half long, operating twelve motor cars with trailers. There are three direct-coupled 225-kilowatt units, the engines being of the Belliss three-crank, horizontal compound type.

The Central London Railway is certainly the most interesting application of electric motive power that has yet taken definite shape. The tunnel line is six and one-half miles in length, and accommodates a double track. Thirty-two electric locomotives will be employed, and the average weight of each train, exclusive of locomotive, will be 105 tons. A three-phase, third-rail system will be employed. The power plant consists of six 850-kilowatt Thomson-Houston generators coupled direct to Reynolds-Corliss cross-compound condensing engines. Current is supplied at the station at 5000 volts, and is transformed to the working line pressure of 500 volts by means of rotary converters in substations along the route.

The principal locomotive dimensions are as follows:—

Number of driving wheels	8
Total number of wheels	8
Diameter of wheels	40 in.
Centre to centre of trucks	14 ft. 8 in.
Total wheel base	20 ft. 4 in.
Total length of locomotive	29 ft. 8 in.
Total height	9 ft. 4½ in.
Weight on each wheel	about 4 tons.
Total weight of locomotive (approximate)	35 tons.

AN ELECTRIC SHUNTING LOCOMOTIVE ON THE WATERLOO & CITY RAILWAY. BUILT BY MESSRS. SIEMENS BROS. & CO., LTD.

Maximum draw-bar pull at starting	14,000 lbs. (6.2 tons).
Draw-bar pull running at 22 miles per hour	8,000 lbs. (3.5 tons).

It may be said broadly that British practice has followed fairly closely the best American lines. Indeed, it can follow only the best, for the stringent rules of the Board of Trade and the general distaste for any temporary or rough construction have prevented any but the highest standard of material and workmanship being even attempted.

The necessity of keeping up voltage at all points of a line has occasioned a most careful study of the most efficient systems of bonding, and of the problems involved in distribution of current along the route.

The general use of roof seat cars has necessitated the evolution of a novel and heavily insulated trolley, mounted on a standard from 5 to 6 feet above the car roof. This trolley is so arranged as to swivel both at the butt of the trolley pole and at its head. Where span-wire is not allowed and the trolley wire is supported by brackets of a fixed maximum length, the trolley must have play sufficient to follow the wire away from the normal position and in either direction. On many roads the trolley wire is at points 8 feet to one side of the nearest rail, and on some lines the trolley has had to run under a wire 12 feet out of normal. To the eye, this method of operation, combined with the low and narrow cars employed, is the most distinct characteristic of British lines.

The universal girder rail, with extremely narrow and shallow groove, has proved a most fertile source of annoyance. The life of wheels is, therefore, exceedingly short, and their cost correspondingly great.

Up to date, the speed limit fixed by law has been extremely low. But one electric tramway has as yet secured permission to run at as high a rate as ten miles an hour, and that only on a suburban road where there is comparatively little traffic.

That there will be a wide extension of electric tramways throughout Great Britain is, undoubtedly, true. But there is not the slightest evidence that any "boom" is likely to occur. The progress will be quiet and steady, compared with that made either on the Continent or in America. The British public is by no means educated up to believe that a tramway of any kind whatever is necessary to its happiness and well-being, and it will acquire that education only by degrees.

The difficulty in obtaining way leaves through principal residential and business centres is enormous, and will be abated only as conviction comes from personal observation. The popularity already attained by such lines as those at Bristol and Dublin will do much to popularise the electric tramway; but both corporations and companies must, of necessity, move with deliberation. The tramway is still the "poor man's carriage" in Great Britain, and it will take years before it will reach its proper estate and be recognised as an indispensable convenience by all classes.

A STUDY IN TRANSPORTATION METHODS NEAR BILBAO, SPAIN
THE ELECTRIC CAR, THE DONKEY, THE STEAM RAILROAD, AND THE CANAL

BUILDING AN ELECTRIC RAILWAY

AN OUTLINE OF AMERICAN REQUIREMENTS AND PRACTICE

By Lemuel William Serrell, M. E.

THOSE who project electric railways have in mind the establishment of a business enterprise from which they hope to make money, and as the proper construction of an electric road has much to do with its earning capacity, it is not only necessary to exercise vigilance in the management of a railway property to take care of fixed charges and dividends, but to so supervise the construction and equipment of the road that the cost of maintenance will be a minimum.

Three things should be observed in the construction of an electric road in order to insure its success:—

First, the road should be located in a territory where the population is sufficient to warrant the expectation of receipts large enough to pay operating expenses and fixed charges from the start.

Second, the charter under which the railroad is constructed, and its franchises, should be approved by competent legal authority to insure the safety of the investment.

Third, the road should be constructed in a thoroughly substantial manner throughout to meet the requirements of the travel that is to be expected, and to keep the repairs and maintenance at a minimum.

At the present time railroads have been constructed in almost every conceivable place, so that it is possible to secure statements of earnings of rail-

THE BEGINNINGS OF CONSTRUCTION. LAYING TIES

roads already in operation, both for city, suburban and interurban travel. The projectors of railroads should, therefore, look up some railroad running through a territory similar to that through which they desire to build, and, by making a comparison and study of the conditions of travel, determine, with as much accuracy as possible, what the probabilities are of the road paying.

This having been determined, legal authority should be sought so that the law may be complied with in all matters relating to charter, proper consents, rights of way and franchises. This is the groundwork upon which the safety of the investment is built. Unless these details are properly attended to, the investor may awake some morning to find that the securities held by him have become valueless or unnegotiable because some lawsuit has been started affecting their validity.

It is very seldom that a railroad is built without going into the money market for financial assistance, and those willing to furnish money for such construction will not do so unless they are satisfied that the location is a good one and that all legal details have been properly attended to. It should also be borne in mind that there is competition in the money market, as in other marts of the world, and that the dealer in bonds must have a security that will be attractive to his clientel.

Investors desire primarily a safe investment, and when they purchase bonds, they do not care to be bothered with them any further than cutting off and collecting the coupons; and in these days when bonds are on the market bearing 4, 5 and 6 per cent. interest and running from 30 to 50 years with no redemption clause in the mortgage outside of the obligation to pay the principal at maturity, those who project electric railroads will find that they must offer something equally attractive if they would hope to secure means for the construction of their road. Their bonds should, therefore, be made to run as long a time as possible,—not less than 30 years,—and the redemption clause to redeem the bonds after a period of, say, 10 years at a premium, should be left out.

The laws under which electric railways are constructed naturally vary in different places. In New York

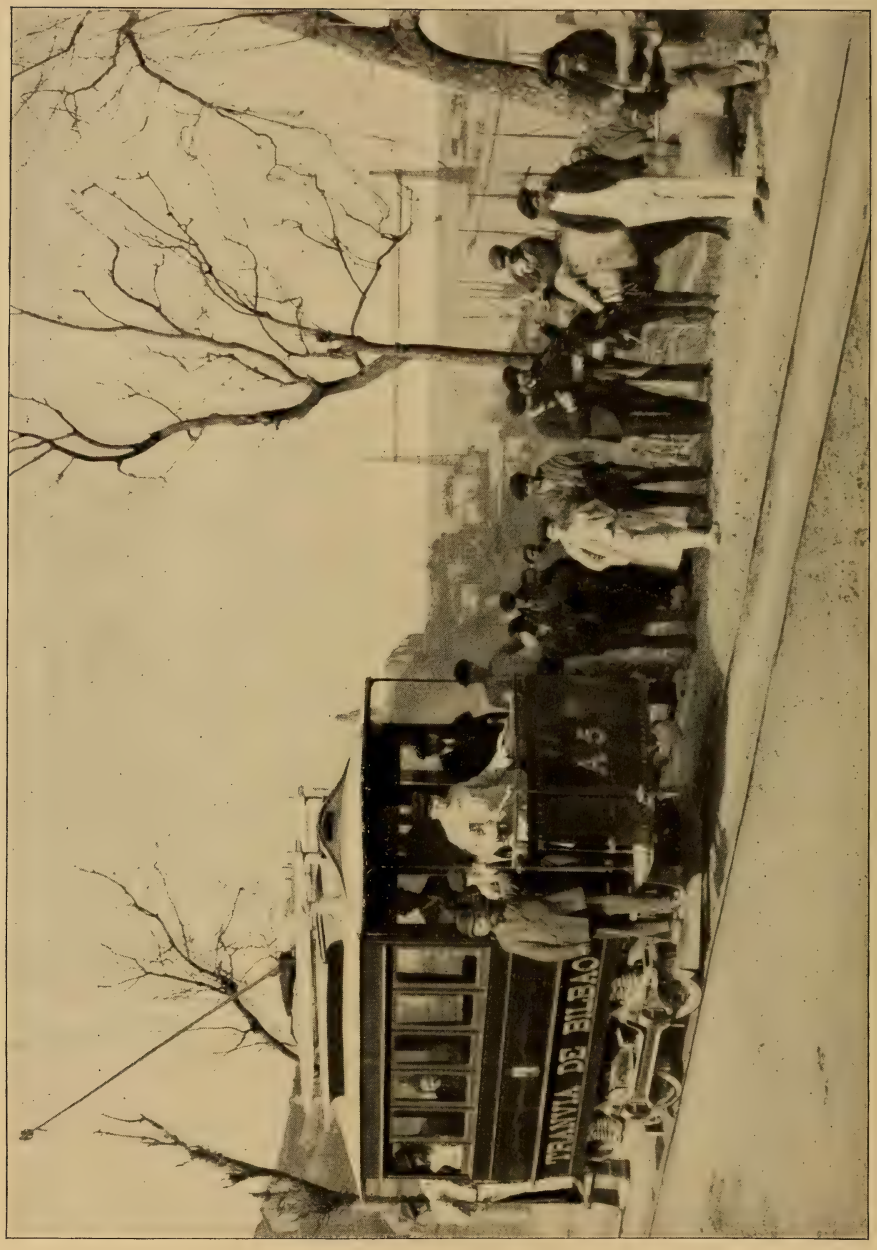
State, for example, after securing a charter, the consent of the railroad commissioners to build must be secured; franchises from all the municipalities through which the proposed road is to run must also be obtained, and in cities the consents of the property owners in amount equal to 75 per cent. of the assessed valuation of the property along the route of the railroad, and 50 per cent. of the assessed valuation in the country, must be secured before the road can be built. In New Jersey there is no board of railroad commissioners. The consents, however, of the majority of the property owners, as represented by foot frontage along the line of the road, must be secured before the franchises in the municipalities can be obtained.

A CONSTRUCTION TRAIN

In most of the New England States it is unnecessary to secure property owners' consents. The State charter and municipality franchise are all that is required. Massachusetts laws, however, are quite rigid; here the consent of the railroad comissioners must be secured as well as their approval of the plans and specifications for building. The amount of securities that can be issued upon the road, both in bonds and stock, is determined by the railroad commissioners, and this amount is based upon what they estimate the road will cost to construct. Excessive watering of the securities is, therefore, practically impossible. One of the results of this law shows that the average capital stock per mile of track is about $23,000, and the total amount of bonds issued per mile of track, about $19,000. The railroad commissioners' reports show that none of the roads in the State are defaulting in the interest on their bonds, and that the total dividends on all the capital stock outstanding, taking every road in the State, were about 5½ per cent. The surplus earned on the same basis was about 4½ per cent. of the total capital.

In Rhode Island and Connecticut charters have to be secured originally from the legislature, which meets every two years, and in Connecticut steam railroad corporations are supposed to have been instrumental in securing the passage of laws making it difficult to build electric railroads parallel to them.

This meagre information will give those contemplating building electric railroads a little insight into the many technicalities that have to be looked



AN ELECTRIC RAILROAD AT BILBAO, SPAIN. EQUIPPED BY THE ALLGEMEINE ELEKTRICITÄTS GESELLSCHAFT, BERLIN. IN THE BACKGROUND CAN BE SEEN THE BAY OF BISCAY AND THE FAMOUS SUSPENSION BRIDGE AT THE PORT OF BILBAO

after before actual construction is begun, and should impress upon their minds the need of necessary legal guidance to carry them through this portion of their work.

These matters, however, having been carried out, the actual construction of the road can be considered. This construction should be done in a thoroughly substantial manner, and, in order to secure the best results, proper engineering authority should be consulted so that the money expended may be put where it will do the most good, avoiding all unnecessary frills and

PHOTO BY BARNETT, JOHANNESBURG

TROLLEY LINE AT PORT ELIZABETH, SOUTH AFRICA

securing a construction that will keep the cost of maintenance at a minimum.

Street railway tracks, when once laid, cannot be repaired without taking up the street pavement, and as this is usually expensive, great care should be taken in first putting down the track so that the roadbed will maintain its alignment. To accomplish this not only must the ties be well tamped and laid on solid ground or ballasted in case of heavy travel, but they should be of a size and number sufficient to provide about 300 square inches of bearing surface under them per running foot of track. Standard oak steam railroad ties, spaced 14 ties every 30 feet of track, make what is considered the most approved construction. These ties are 6 inches thick, 8 inches face and 8 feet long. It is well to bear in mind that if a road is to earn dividends one cannot afford cheap track construction.

The latest practice for city work in the United States is to excavate a trench to a depth of from 4 to 6 inches below the bottom of the tie, fill this space with broken stone, well compacted in place by running a steam roller over it, and then lay the track upon this foundation, tamping and ballasting with broken stone. After this the street is restored to its original condition. The statute in most places requires the railroad company to pave between their tracks and 2 feet on each side of them with the same material used in paving the rest of the street.

In cities where the street is paved, or

THE ELECTRIC RAILWAY AT CAIRO, EGYPT, EQUIPPED BY THE UNION ELEKTRICITÆTS-GESELLSCHAFT, BERLIN

is likely to be paved, with block pavement, the rail used must be of sufficient height to allow the pavement to be put in above the ties. The standard rail now used for this purpose is of the girder form, 9 inches high, weighing from 90 to 100 pounds per yard, usually in 60-foot lengths with 12-bolt joint plates. The tram of this rail should be grooved and have a wide flange coming up flush with the pavement, which prevents the edge of the paving stone wearing away by heavy trucking. Brace tie-plates, to keep the rail from spreading, should be put in at intervals of not more than 10 feet.

Grooved rails are very troublesome when used on dirt or macadamised streets or on roads with infrequent service, as the dirt and broken stone get in the groove, making the derailment of the car possible, and in cold weather water in the groove is apt to freeze, producing the same trouble. As it is standard practice to use the rails for the return circuit, great care should be taken in bonding the joints together so that the track construction offers the path of least resistance for the return of the current to the power station. If this is not done, the current is likely to escape to water pipes, gas pipes and underground wires.

Several examples of bad bonding have come to the writer's attention. In one instance a steam boiler in a particular factory deteriorated very rapidly. The boiler was of the horizontal return tubular type, and it seemed difficult to get a boiler with more than one year of life. With suitable instruments it was found that an electric current flowed through the boiler, and by watching these instruments the location of the car upon the line could be quite accurately determined. The water pipes in this particular city were subject also to electrolytic action, and in some cases were eaten away or filled with small holes. In another case sufficient current was taken off a telephone in a house when

connected up with a gas pipe to run a low-tension arc lamp.

These phenomena can be overcome where the rails are properly connected together. The use of 60-foot rails is, moreover, preferable, as it reduces the number of bonding connections one-half. There are many devices on the market to bond rails together, all of which have more or less merit. The particular thing to be borne in mind, however, is to so connect the rails that the conductivity through the joint is as great as through the rail itself. This can be secured only by having bonds whose sectional area, together with the actual contact with the metal of the rail, has a conductivity equal to that of the rail itself. This, when once secured, practically eliminates electrolytic action at the joint and the other troubles mentioned, provided the bond is put in place dry and tight.

For suburban and interurban roads, a track built of *T*-rail, spiked direct to ties, is the best form of construction that can be secured for dirt or macadamised thoroughfares. After laying this track in macadamised streets, the macadam should be replaced, rolled down, and new screenings put upon it, relaying the macadam so that it covers the rails to the depth of one-half inch after being thoroughly rolled. It should stand thus until the road is ready to open for traffic, at which time the surface of the rail should be cleaned and a small groove dug on the inside of the rail just large enough to admit the flange of the car wheel. A road thus constructed is one of the best roads that can be made to drive over without racking a carriage. A 60-pound *T*-rail is usually heavy enough to use, although for long cars, or frequent service, a 70-pound rail is preferable.

ANOTHER VIEW ON THE CAIRO RAILWAY

The overhead construction is of two forms,—span wire and bracket arm.

THE ELECTRIC RAILWAY AT MADRAS, INDIA, EQUIPPED BY THE ELECTRIC CONSTRUCTION CO., LTD., WOLVERHAMPTON, ENGLAND

A MOTOR CAR AT BERLIN, CONN., U. S. A., ON THE NEW YORK, NEW HAVEN & HARTFORD RAILROAD

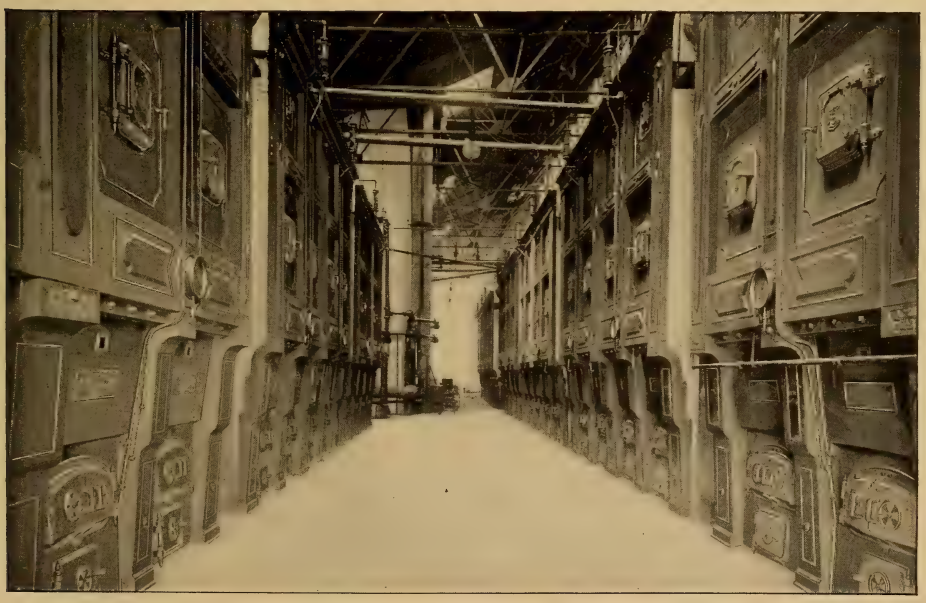
In the first, the trolley wire is hung from a span wire stretched between the poles, and in the second a single row of poles is used, with brackets extending from the sides to support the trolley wire. The latter should be attached to the bracket arm in a flexible manner to take away the knocking blow of the

trolley arm on the car when passing under the bracket.

Where iron poles are used for span-wire work, they should weigh about 700 pounds and be made of 7, 6 and 5-inch pipe, welded together at joints, the outer pipe overlapping 18 inches. Larger poles should be used to support curves at corners. When wooden poles are used, a very neat form of construction can be obtained by using octagonal yellow pine poles. These do not cost much more than the ordinary chestnut pole, and are much more sightly. For span-wire work it is preferable to use a pole with a 9 inch top and 12-inch butt.

The amount of feed wire required to operate a road depends upon the number of cars to be operated, the length of the line, and the steepness of the grades and their location. Much money is often wasted by getting more feed wire than is needed, and often the equipment is injured by not providing enough. The easiest way to determine the most economical amount of feed wire needed to operate any given road is to plot the road graphically. This may be done by taking a profile, placing the number of cars to be used in their average conditions of service upon line, determining the loads, or the amount of current to be supplied, at various points, and erecting ordinates at these different points to represent the amount of copper needed to supply the required amount of current at a uniform loss of, say, 10 per cent. The curve of areas for feed wire obtained in this way will approximate a parabola. By using feed wires of various lengths and sizes, this theoretical curve can be reproduced very closely in actual practice. This plan, which was originated by the writer some years ago, has been used by him with great economy in all of his work.

Several elements enter into the design and construction of a car house. The building should be preferably made fireproof, and at the same time should be so arranged that the cars can be easily handled and repaired. An iron-frame building, covered with corrugated iron, is fireproof, and costs only about one-third more than a wooden building upon the same foundations. To secure

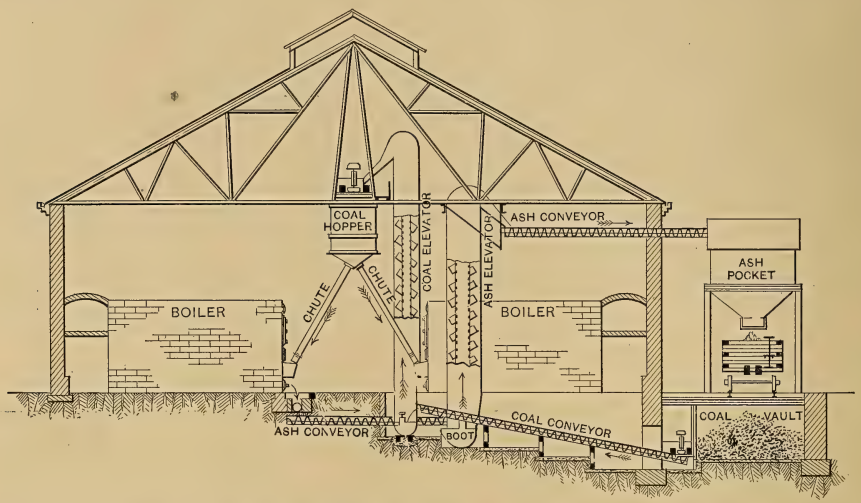


A 6000 H. P. BOILER PLANT, INSTALLED BY THE STIRLING BOILER COMPANY, OF CHICAGO, AT THE POWER HOUSE OF THE WEST CHICAGO STREET RAILWAY COMPANY

the lowest rates of insurance, the building should be made of either iron or brick and have concrete floors.

Every track in the building should have its own doors and entering curve, and the tracks inside of the building should slope from the rear to the front about 15 inches in 100 feet. This slope is just sufficient to allow the cars to stand still when the brakes are off and yet permit of the car being pushed out of the building by one man in case of fire.

The trolley wires running into the building should also be arranged with



CROSS SECTION OF BOILER ROOM ON OPPOSITE PAGE, SHOWING TRANSFER OF COAL FROM CAR TO BOILERS, AND OF ASHES FROM BOILER TO CAR

a section insulator and a switch located upon the pole outside of the car house, so that the current may be cut off from the wires inside the car house at will. A conductors' room, containing lockers, a repair shop with the necessary tools, and pits under some of the tracks should also be provided, and a clock with an illuminated face set in the front gable of the carhouse will enable the conductors to keep their watches set to a standard time, quite necessary for the satisfactory operation of the road. It is also well to provide fire hydrants at convenient places near the building, and hose that can be readily attached.

A separate building should be provided, made of brick and iron, about eight or ten feet square, in which may be stored all oil, waste and other inflammable materials. This building should not be located within fifty feet of the car house. It should be remembered that even though that building may be fireproof, the cars are inflammable, and the adoption of the suggestions made here is inexpensive, lessens the fire risk, and reduces the cost of insurance.

No set rule can be made for the proper design of a power station. The question of the location so that coal, water and real estate may be secured cheaply, and that current can be distributed with the least cost and expense for feeders, should all be taken into careful consideration by a man experienced in this work, whose advice will secure the greatest economy in first cost and in operation.

The difference in cost of power per car-mile in different locations is very remarkable and is probably due to the inexperience of those who have designed and constructed power stations. The cost, in fact, varies nearly 500 per cent., as shown by the annual reports of the railroad commissioners of New York and Massachusetts. It appears from these that of nineteen companies, operating less than 250,000 car miles per

BOILER ROOM IN THE POWER HOUSE OF THE UNION TRACTION COMPANY, OF PHILADELPHIA SHOWING COAL AND ASH HANDLING MACHINERY AND OVERHEAD STORAGE HOPPER, DESIGNED AND INSTALLED BY THE LINK-BELT ENGINEERING CO., NICETOWN, PHILADELPHIA

annum, four obtain their power at less than 2 cents per car-mile under average conditions of load, track, etc.; six, at between 2 and 3 cents; five, at between 3 and 4 cents; one, at between 4 and 5 cents, and three at more than 5 cents. Of five companies operating over 5,000,000 car-miles per year, one obtains its power at less than 1 cent a car-mile; three, at between 1 and 2 cents, and one, at between 2 and 3 cents. The Brooklyn Heights Company, at Brooklyn, N. Y., have the cheapest power,—8.6 mills per car-mile,—and the road at Binghamton, N. Y., comes next with 9.4 mills. Cheapness of coal at the given point is, of course, a factor in the price of power; but the controlling one seems to be good, sound common sense in electrical engineering.

If power can be secured from a local electric light company, situated in an advantageous position for the distribution of the current, it will usually be found that small roads, operating less than ten cars, can make more advantageous terms than if they produced the power themselves. This is due to the fact that the electric light company has the boiler capacity and can furnish the power without much increase in their payroll account. It is customary to make a charge for power upon a car mileage basis, and electric light companies can usually furnish power for less than three cents a car-mile and make money.

The power station should be located, if possible, about the centre of the line, and sufficient power should always be installed to have ample reserve in case of necessity. Without attempting to go into the details of power station work, a few suggestions may be of value here. The day of belt-driven generators is practically over, and the direct-driven generator is considered best practice. The size of the power station depends upon the number of cars to be run and the grades to be surmounted. Under ordinary conditions the amount of power installed in a power station should not be less than 40 horse-power per car for roads operating ten cars or

A VIEW OF SOME OF THE OVERHEAD EQUIPMENT ON THE DOUGLAS AND LAXEY ELECTRIC TRAMWAY, INSTALLED BY MESSRS. MATHER AND PLATT, LTD., MANCHESTER, ENGLAND

less. Large roads find that an installation of 20 horse-power per car is often sufficient for all purposes. It is well, however, to install an auxiliary unit if funds can be provided for the purpose. The cheapness with which electric machinery may be purchased at the present time makes it unwise to install units of less than 150 kilowatts capacity.

One should never attempt to condense the steam if water for condensing has to be purchased, as condensing requires from twenty to thirty times the amount of water evaporated in the boiler. Neither should a compound engine be run non-condensing on railway work unless the units are large, and for roads using a small number of cars a compound engine, running condensing, should never be used on account of the great percentage variation of load. Economy, however, can be effected by using a single-cylinder engine running condensing. Railway station engines should always be made heavier than engines used for ordinary purposes.

The steam piping should be so designed that the steam from any one of the boilers may be supplied to any engine in the station at will, and the arrangement of the exhaust piping should provide for the utilisation of the exhaust steam and the heating of feed water. Where condensers are used, an atmospheric exhaust should also be provided, with a proper relief valve, so that the steam may exhaust automatically into the atmosphere in case of accident to the condenser.

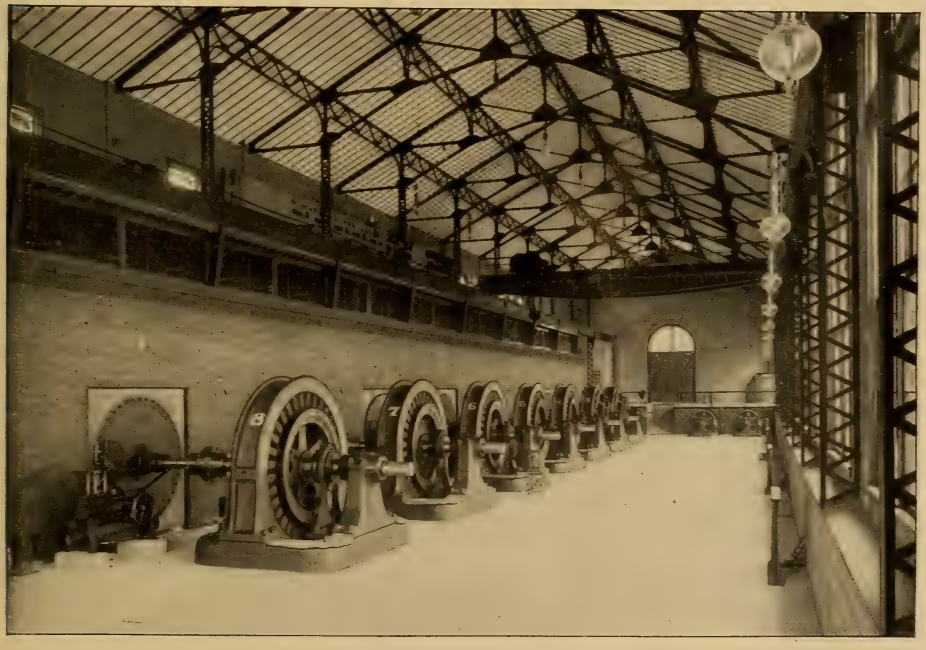
Great care should be given to the selection of equipment. The cars, being that portion of the railroad which

the public uses, should be attractive, comfortable and properly heated in the winter time. Care for the comfort of the passenger always increases the receipts of the road.

The standard car for single trucks is an 18-foot body, with platforms at each end about 4 feet wide. It is dangerous to attempt to run single-truck cars at a high rate of speed on account of the oscillation and the liability to jump the track. A double-truck car body cannot be shorter than 22 feet, as this length is required for trucks and their brake mechanism. Many of the cars in use in larger cities at the present time are of the double-truck form, having run the car at slow speed in the city and at high speed in the suburbs. This is accomplished by equipping the car with four motors, one on each truck axle, which motors are so connected with the controller that they may be all thrown in series for slow speed and in parallel for high speed. The motors used on the cars are each capable of developing about 30 horse-power.

Electric cars average about 150 miles per day, and the cost of operating them, including all expenses except interest, varies from $12 to $20 per day.

Electric railroads have suffered much criticism during the past few years because many of them have been over-



THE ST. ANTHONY FALLS POWER HOUSE, SUPPLYING POWER TO THE STREET RAILWAYS OF MINNEAPOLIS AND ST. PAUL, MINN., U. S. A., ERECTED BY THE GILLETTE-HERZOG MFG. CO., OF MINNEAPOLIS

bodies about 33 feet long, and they are the most economical to use as they carry more people, require very little more power to operate, and can be manned with the same crew required for a small car. Many of these long cars are used for both city and suburban work, the same car performing both duties, and it is, therefore, necessary to be able to capitalised, and have either gone into the hands of a receiver on this account or are struggling along under a burden which is hard to carry and likely to result in a receivership. On the other hand, it is surprising to note what erroneous ideas the public in general have regarding the cost of electric railroads and their capacity to make money.

ALONG THE LINE OF THE DOUGLAS & LAXEY ELECTRIC TRAMWAY, ISLE OF MAN

AN ELECTRIC RAILWAY IN BAHIA, BRAZIL, BUILT BY MESSRS. SIEMENS & HALSKE, BERLIN

The impression seems to prevail amongst the uninitiated that an electric railroad can be built and equipped for about $6000 per mile, and that in no case should the cost exceed $10,000 per mile, while they also unwisely imagine that an electric railroad can be built anywhere and still be successful in making money.

It is true that some railroads are built through unproductive territory and are successful, but this is on account of their terminal facilities. Interurban roads are proving a much better investment than they were, at first, thought to be.

A CAR ON THE SNAEFELL MOUNTAIN RAILWAY IN THE ISLE OF MAN, EQUIPPED BY MESSRS. MATHER & PLATT, LTD.

Such roads usually make more money where they run between towns of different sizes than they do running between towns of about equal size; that is, the probabilities are that a railroad running between two cities, one of 20,000 population and the other of 10,000 population, will earn more money than a railroad running between two cities having 20,000 population each.

A few facts regarding what an electric railroad must be able to do in order to make both ends meet will be interesting. Under ordinary running conditions one car is required for every mile of distance to be travelled so as to maintain a headway of from 12 to 15 minutes. Very few roads pay where the conditions of travel are not sufficient to warrant more than four cars in service. The cost of running an electric car varies between $3500 and $4000 per annum. This means that each car must carry about 80,000 passengers per annum at 5 cents per passenger in order to simply pay operating expenses, and this number must be increased by about 25,000 additional passengers in order to pay 6 per cent. on an investment of $20,000 per mile, which is a fair average investment to represent the cost of roads in cities of about 50,000 people where the conditions of travel do not warrant over an eight to ten-minute service and expensive paving does not have to be put in by the railway company. Sprinkling cars are now in use on many railroads

and their operation adds much to the comfort of the passengers, particularly along roads that are likely to become dusty. In such places the speed of the cars is usually great, and unless the tracks are sprinkled, the passengers become covered with dust. In warm weather many people enjoy an outing on an open electric car, and the use of a sprinkler has been found to increase this excursion travel to an extent sufficient to more than pay the expense of running it.

Many people have erroneous ideas on the question of freight transportation, and imagine that electric roads, equipped to carry freight, will prove great money-makers. Freight transportation pays in some cases, but it should be borne in mind that the freight business is very different from the passenger business. In the latter case people get on the car and pay their fare, and that ends it; but with a freight business all shippers are continually bargaining to secure better rates with the promise of increased shipment. To diplomatically cope with these shippers, keep their business and maintain the rates, requires a man of rare tact and executive ability, whose services are worth more money than such electric railroads can usually afford to pay.

It should be borne in mind that electric railroads are primarily collectors and distributors of people over short distances for cheap fares, and while some freight roads have been built and made to pay, they are the exceptions to prove the rule.

Electric railroads can scarcely hope to be successful competitors with steam railroads when they are located upon a highway and when the distance between cities exceeds twenty miles. If, however, they are located upon private rights of way, they can hope to compete with steam railroads for their passenger business over distances in excess of the above. In this latter case, however, those who imagine that they can likewise compete for freight, should be undeceived, unless it should be of a local nature, as the combinations of steam railroads in existence will crush all profit out of this branch of the business.

OVERHEAD CURVES AT A CAR HOUSE

OVERHEAD CONSTRUCTION

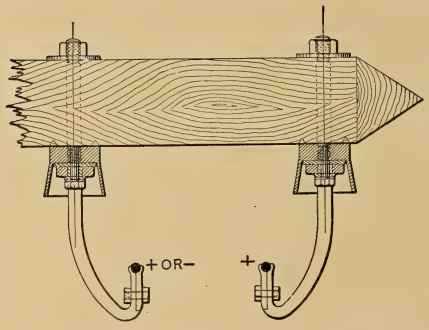
By J. G. White

THE history of electric railroading contains many curious facts, one of which is that systems using the underground conduit and the third rail, now so successful, were tried and abandoned before any attention was paid to the overhead trolley, which, up to a year or two ago, was the only system which had proved its value conclusively. Another interesting fact is that the modern trolley road has no such thing as a trolley about it, if we adhere to the meaning which the word had before the electric railway gave it a new significance. A trolley is literally "a little car," and the term was correctly applied to the little four-wheeled car which ran on top of two parallel overhead wires on some of the earlier roads, before the development of the underrunning wheel with its pole and base, which is now known generally as a "trolley."

The history of the electric railway using a conducting system of any type begins in 1851, when Moses G. Farmer built a small model railway for which current was supplied from a stationary battery through the rails to a very primitive type of motor mounted on the car. This method of distribution through rails appears to have been looked upon for many years as the most feasible one. A French patent, issued to Bessolo in

THE ELECTRIC RAILWAY AT ASBURY PARK, N. J., U. S. A., IN 1887. SPAN WIRE CONSTRUCTION WITH TWO TROLLEY WIRES, POSITIVE AND NEGATIVE, AND A FOUR-WHEELED TROLLEY RUNNING ON TOP OF THESE WIRES. CONNECTION WITH THE CARS WAS MADE BY FLEXIBLE CABLE

1855, provided for the delivery of current either through a third rail or an uninsulated overhead conductor. No experiments on the operation of a railway on a practical scale were possible until the demonstration of the reversibility of the dynamo-electrical machine in 1873, which opened the way to the development of the modern motor. After this time various inventors began working on the railway problem on a larger scale, as it then became possible to build something more than mere toy models.



INSULATED HANGERS FOR THE TWO OVERHEAD CONDUCTORS, POSITIVE AND NEGATIVE

The first experimental electric railway was installed at Berlin in 1879 by Messrs. Siemens & Halske, operating upon the third-rail system, and the first commercial line was opened in 1881 at Lichterfelde, Germany, operated also upon the third-rail system. Messrs. Siemens & Halske in 1881 exhibited at the Paris Exposition an electric car operating on the first form of overhead trolley system of which there is any record. In this case a trolley wire was not used, but a system which is, in principle, the same as that afterwards developed by the General Electric Company in the United States for use in the Baltimore Belt Line tunnel, namely, a tube, slotted at the bottom, in which a contact shoe is drawn along by the moving car.

In 1883 another successful line was opened in Ireland,—the Portrush road,—again using the third-rail system. That year also marked the first introduction of electric railways in the United States by an experimental car exhibited at the Chicago Railway Exposition.

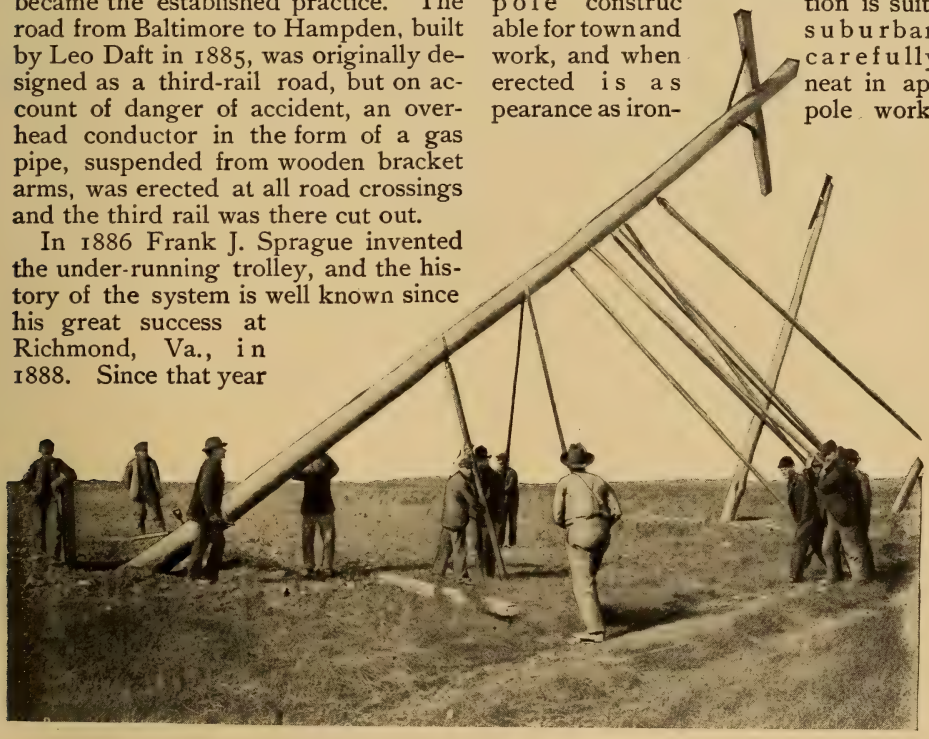
In 1884, before the erection of the first trolley wire, Messrs. Bentley & Knight, in the United States, built their conduit line at Cleveland, and this was

almost immediately followed by the Henry line at Kansas City, where a No. 1 hard-drawn copper trolley wire was used. This road was tried both as a double-trolley (positive and negative) line, and as a line with positive trolley and negative return over the rails. Its trolley, however, was of an over-running type. This use of copper trolley wire seems to have been successful, but there was an almost immediate step backwards in the railway conducting system design by the adoption of a small silicon-bronze conducting wire, and it was not until about 1892 that the use of hard-drawn copper trolley wire became the established practice. The road from Baltimore to Hampden, built by Leo Daft in 1885, was originally designed as a third-rail road, but on account of danger of accident, an overhead conductor in the form of a gas pipe, suspended from wooden bracket arms, was erected at all road crossings and the third rail was there cut out.

In 1886 Frank J. Sprague invented the under-running trolley, and the history of the system is well known since his great success at Richmond, Va., in 1888. Since that year the overhead construction for electric railways has not changed materially as to system or general form, the development having been in the direction of improved details and increased strength and durability.

Overhead construction resolves itself naturally into the iron-pole and the wooden-pole types. These are again subdivided into span wire or cross suspension and bracket construction, and the wooden-pole type may be divided into octagonal and round-pole construction.

Iron-pole span construction is the most durable and expensive type, and is suitable for the best class of city work. Bracket construction is not ordinarily desirable in cities unless there are exceptional conditions, such as a park in the centre of the street, which permits the pole to be set out of the line of traffic without an undue length of supporting bracket. The octagonal wooden-pole construction is suitable for town and suburban work, and when carefully erected is as neat in appearance as iron-pole work.



RAISING A POLE WITH PIKE POLES

Round wooden poles are suitable for less pretentious suburban roads, and are as satisfactory as the octagonal poles, except for their appearance.

Bracket construction is desirable for suburban work or other places where it can be used, as it is somewhat cheaper and is fully as durable, the supporting

A WIRE GANG AND CONSTRUCTION CAR

DOUBLE TROLLEY WIRE OVER SINGLE TRACK, WITH TURNOUTS

structure not being put under the strains that are necessary to keep span wires taut and in good condition. Care should be taken in designing bracket construction to secure a flexible form of suspension for the trolley wire, as an insulator, bolted directly to the bracket, forms too rigid a support and results in the breaking of stud bolts and injurious sparking at the trolley wheel.

The sizes of poles have undergone the same steady increase that has occurred in the case of the trolley wire. The iron poles in use eight or ten years ago frequently weighed 500 pounds or less, and were usually badly distorted by the strain of the wires. The standard poles of to-day in American practice weigh not less than 700 pounds for straight line construction and not less than 1000 pounds for corners where greater strains occur. These poles are usually made up of three sections of pipe (the standard poles of 6, 5 and 4-inch pipe), the smaller sizes being inserted in the larger for a length of 18

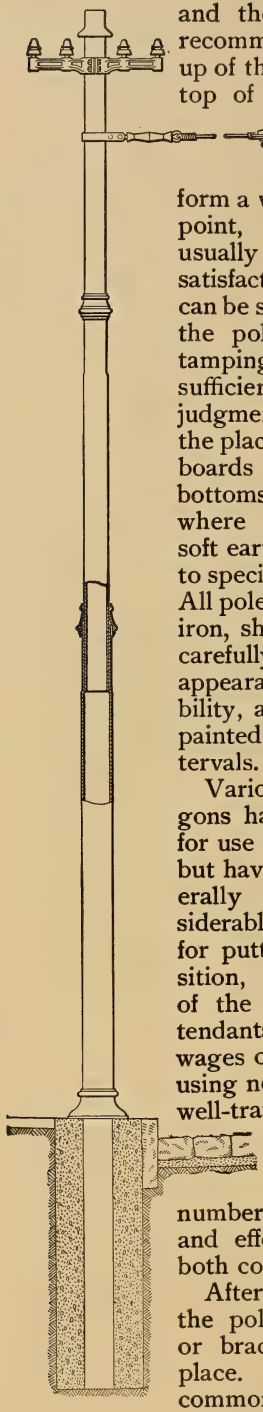
inches, and the outside pipe being swaged down at the place of insertion to clamp the inner piece firmly. In addition to this a wrought iron band is frequently shrunk on at the top of the joint to prevent the possibility of the outer pipe being split under strain. A neat ring of cast iron is usually dropped over the top of the joint to improve the appearance, and an acorn-shaped cap is put on the top of the pole to give a further finished effect.

Iron poles should always be set in a good quality of concrete, preferably made of Portland cement, sand, and broken stone or gravel in suitable proportions, and this concrete should be thoroughly rammed in layers when the pole is being set. Great care should be exercised in the erection of span poles, to give them a proper rake away from the street, so that the tension of the span wires will bring them nearly to a vertical position. No small amount of skill is required to set a line of poles in a straight and level street so that, after the span wires are erected and the poles pulled up to their final position, they will be absolutely in a straight line and with their tops on the same level. This is, however, one of the most important requirements of a sightly overhead line.

The kind of wooden poles in most common use in the United States are Georgia pine, chestnut and cedar. The sizes in use have increased from 6 or 7 inches diameter of tops up to 10 inches or larger. A good quality of Georgia pine, neatly sawed to an octagonal form, and with the butts treated with tar or creosote, forms the most sightly type of wooden-pole construction and appears to have as long a life as any, although the comparative youth of the whole art is such that the matter of durability is not as well understood as could be wished.

It is probable that setting wooden poles in a cheaper grade of concrete, preferably made of natural cement, increases the life of the pole considerably,

A VIADUCT OVER RIVER AND STEAM RAILROAD



A TYPICAL IRON POLE

and the best practice recommends the coning up of the concrete at the top of the ground, finishing with cement plaster to form a water shed at this point, at which decay usually begins. Very satisfactory construction can be secured by setting the poles in earth, if tamping is done with sufficient care and good judgment is exercised in the placing of cross keyboards at the tops and bottoms of the holes where poles are set in soft earth, or are subject to specially heavy strain. All poles, either wood or iron, should be painted carefully for the sake of appearance and durability, and should be repainted at suitable intervals.

Various derrick waggons have been devised for use in setting poles, but have not been generally adopted. Considerable time is required for putting them in position, and the expense of the horses and attendants equals the wages of a gang of men using no machinery. A well-trained gang with pike poles will raise a surprising number of poles in a day and effect a saving in both cost and time.

After the erection of the poles the span wires or brackets are put in place. The span wire commonly used is of galvanised steel, 5-16 in. in diameter, made up of seven strands, which is attached to the iron poles by means of collars, or to the wooden poles by means of eye-bolts.

In iron-pole work a strain insulator, so-called, is cut into the span wire near the pole to provide an additional insulation between the trolley wire and the pole. This usually takes the form of a piece of hickory or locust 6 or 8 inches long, with a cap and eye shrunk over each end, or a pair of short eye-bolts mechanically connected, but electrically insulated by some suitable form of compound. This compound is of the same nature as that used in supporting the trolley wire, and is made up of different substances by different manufacturers, the base usually being hard rubber, mica, shellac or asbestos, formed into shape under heavy hydraulic pressure. The span wires are pulled up to the proper tension by means of a block and fall and are then made fast.

Bracket construction usually consists of a horizontal piece of 2 or 2½-inch gas pipe supported by a cast iron scroll, or by a strut of slightly smaller gas pipe, placed at an angle of 45 degrees. These are attached to the poles by castings, which are clamped around the iron poles or bolted to the wooden poles. A most desirable form of bracket provides for a piece of span wire 12 or 18 inches long, on which the ordinary span wire insulator is used for supporting the trolley wire, as illustrated on page 323 This gives a flexible support and forms a species of cushion for the trolley pole in case it should leave the wire and fly into the air.

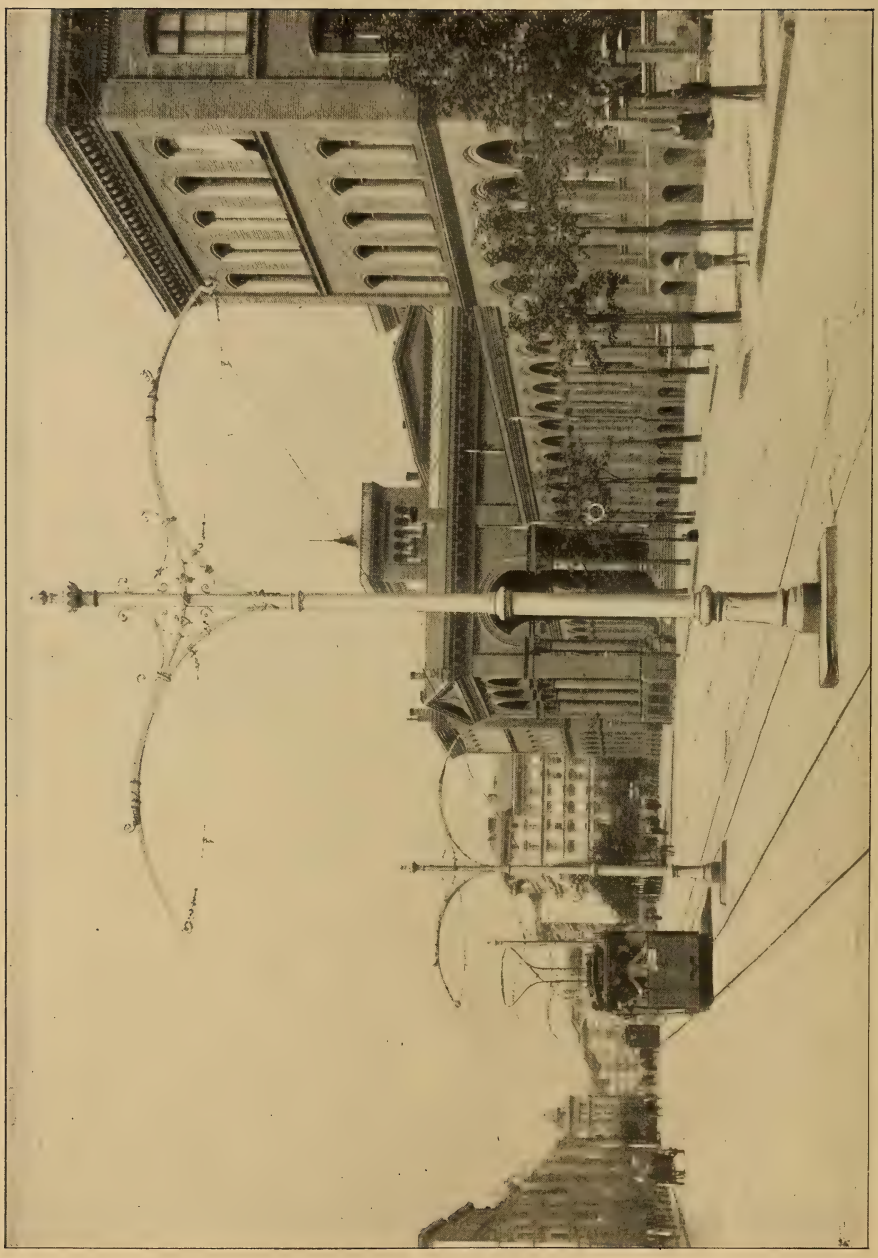
Trolley wire should be furnished in as long lengths as possible, usually one mile to the reel, should be straight and free from kinks, splinters and similar defects, and, of course, should have as high conductivity as is consistent with the necessary tensile strength. The reel of wire is mounted on a reel cart and is followed by a tower waggon, or it is mounted directly on the tower waggon on an axle which permits it to turn readily, with a brake to control the speed of unreeling. As it is moved along the street, the linemen on top of the tower loop up the trolley wire to

OVERHEAD EQUIPMENT AT LEEDS, ENGLAND, INSTALLED BY MESSRS. GREENWOOD & BATLEY, LTD., OF LEEDS

each successive span or bracket with a temporary tie wire. When the end of the reel is reached, a block and fall is attached, the wire is pulled up to the proper tension, and the next reel is run out.

The joint between the different lengths is made with some form of sleeve provided with wedges or other suitable clamping device, the whole presenting a clear path for the trolley wheel, not much larger than the original section of wire. The insulating gang then follows with the insulator or hanger, as it is called, which is attached to the span wire or bracket, and in turn supports the ear or clip, which is attached directly to the trolley wire.

The ear has gone through a kind of evolution, including a great variety of mechanical forms utilising wedges, screws, and other fittings, but the standard form, at present, is a simple brass casting which clamps over the wire, the edges being ground very thin and hammered closely around the wire, no solder being employed, as its use



A SPECIMEN OF GERMAN OVERHEAD CONSTRUCTION AT BERLIN, INSTALLED BY MESSRS. SIEMENS & HALSKE

tends to destroy the temper of the wire and cause it to break.

Pull-off wires and insulators are put on at curves to deflect the wire to the proper position over the track where the trolley wheel will follow it readily, attention being paid to the changed position of the trolley pole and wheel, due to the elevation of the outer rail of the curve. Taps are then put on to connect the trolley wire to the feed wire at suitable intervals, these taps sometimes taking the form of flexible insulated copper wire, one end of which is wrapped around the feeder wire and soldered, and the other end carried along the bracket or span wire to a suitable clip, which makes the attachment to the trolley wire. Another method is to use an insulated span wire, one end of which is attached to the feeder. The trolley wire is connected to it by an uninsulated hanger. This is a neater and more satisfactory form than the other.

Lightning arresters are also placed on the poles at suitable intervals and are connected to the earth to provide a path for the escape of the lightning discharge.

The line is longitudinally anchored at suitable intervals on straight lines and near curves, the anchor taking the form of an extra strong ear, fastened to the trolley wire and guyed in each direction to the nearest poles, so that a break in the trolley wire will not allow it to slip through the span wire hangers and run down for its whole length. The most approved form of anchor ear is supplied with a swivel top, which prevents the strain of the guy wires or bridle wires from pulling the trolley wire out of a straight line.

SINGLE AND DOUBLE-CURVE SUSPENSION CAPS; EAR, CAPS AND CONE FOR TROLLEY WIRE; AND SLEEVE FOR JOINING WIRE

At turnouts and branch-offs overhead frogs or switches are erected, which

guide the trolley wheel on to the proper wire. Overhead switches are always likely to prove troublesome, and in order to dispense with them at the turnouts on single-track roads it is considered good practice to erect two trolley wires a few inches apart over the centre of the single track. At turnouts the proper wire is pulled over the side track, the other wire furnishing a straight path for the car running in the opposite direction and following the straight track. The second wire acts as a feeder as well as trolley wire, and the cost of this additional conductor, used both as a working wire and as a feeder wire, is but little more than the same amount of copper mounted on a cross-arm on the poles as a feeder wire alone.

A STEAM RAILROAD BRANCH OPERATED ELECTRICALLY

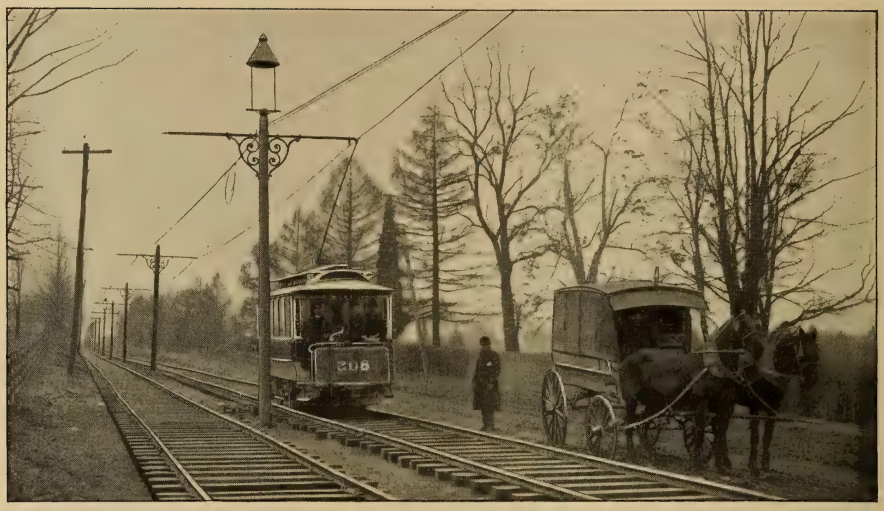
The size of trolley wire considered as standard has steadily increased rrom the No. 4 Brown & Sharpe gauge (No. 6 Birmingham gauge) silicon-bronze in use ten years ago to the No. 0 (the Brown & Sharpe and the Birmingham gauges for this and the several following gauge numbers are practically alike) hard-drawn copper wire which is now commonly used for roads where the traffic is not especially heavy. For city work where the wear is apt to be excessive, nothing less than a No. 00 should be used, and a considerable amount of No. 0000 is being erected, both for city work and for suburban work where the cars are heavy and frequent and the speed is high.

With the increase in number of high-speed lines and the number of lines doing a freight business where locomotives requiring heavy currents are used, considerable difficulty has been experienced in securing sufficient contact on the trolley wire to prevent undue burning of trolley wheels. The life of a trolley wheel on an interurban line is often very short, as it may be cut completely in two from the burning action at the point of contact with the wire. Various devices have been tried to avoid this difficulty, but without any marked success. Two trolley poles in multiple have been found to give too much trouble, and many cars equipped with two trolleys are now running with one of them tied down. The use of some sort of contact shoe which will give a better area of contact with the wire is more likely to prove the remedy than any change in the trolley wire itself.

For such lines some use has been made of figure 8 or pear-shaped trolley wire, the supposed advantages of which are that the form of its lower section gives better contact with the trolley

A SUBURBAN ROAD NEAR BALTIMORE, MD., U. S. A.

OVERHEAD CONSTRUCTION AT DRESDEN, GERMANY. THE ARC LAMP POSTS ARE USED TO SUPPORT THE TROLLEY WIRES. INSTALLED BY MESSRS. SIEMENS & HALSKE, BERLIN



A HIGH-CLASS SUBURBAN ROAD

wheel, and the ears of the supporting clips do not reach down to the bottom of the wire where they can be struck by the trolley wheel, causing a spark which is particularly objectionable in high-speed work.

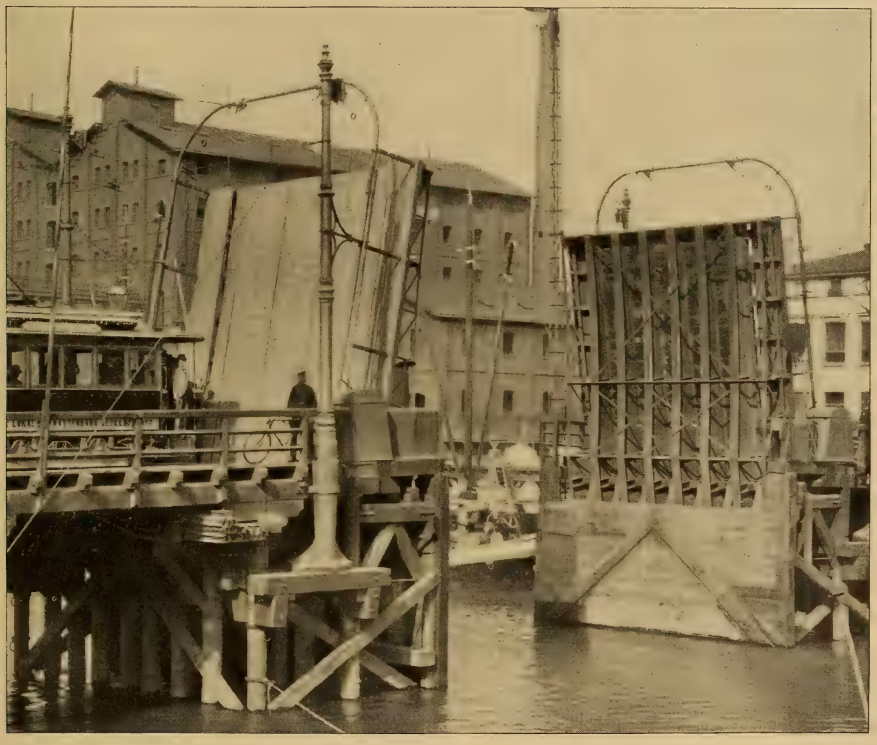
A great deal of difficulty has been experienced in the use of this form of trolley wire. It is an especially troublesome section to draw, and is very likely to have short kinks or long waves which throw the top and bottom out of a vertical line and make it difficult to so erect it that a trolley wheel will run smoothly. On curves it has a special tendency to tip. Altogether, the advantage of this form of wire has been overrated. The same amount of copper in the form of a round wire is much more easily handled. A properly constructed supporting clip, with lips ground to a fine edge, offers little obstruction to the trolley wheel, and the resulting sparking is negligible.

ANOTHER VIEW

It was early seen that the trolley wire alone did not have the necessary conducting capacity for the operation of a number of cars or for one car over a long line. A feeder system was, therefore, adopted which resembled that in use for electric lighting, namely, a small working conductor with supplementary conductors or feeders on the poles, with connection at suitable intervals to the working conductor. The sizes of these feeders were originally worked out with much care, different sized wires being used for different service in order to secure the same electrical pressure at all points of the system, as is done in electric lighting.

After some time it was found that

this refinement was unnecessary, as absolute uniformity over the entire line was not essential, and was, furthermore, almost impossible of realisation, as the starting of cars and operating up-grades made heavy demands on the conducting system which caused great fluctuations. An understanding of this fact led to the adoption of No. 0000 gauge wire, a little less than half an inch in diameter, as the standard. This size was selected as being about the largest of No. 0000 wire. A considerable amount of 1,000,000 circular mil cable has been used for heavy work. This cable is 1 3-16 in. in diameter of wire proper, and 1½ in. in diameter over the insulation. The insulation in common use is known as "weatherproof," and consists of three layers of cotton, braided over the wire, the whole being saturated with an insulating compound. While this is not a high grade of insulation as compared with that required for



A GERMAN LEVER-DRAWBRIDGE FOR ELECTRIC TRAMWAY TRAFFIC, EQUIPPED BY THE ALLGEMEINE ELEKTRICITÆTS-GESELLSCHAFT, BERLIN

that could be handled with facility, the larger sizes being too stiff and unwieldly to be easily erected.

When larger sizes are necessary, a stranded wire or cable is used, which has sufficient flexibility to be handled without great difficulty.

The size in most common use in the United States is known as 500,000 circular mil cable, this being the measure of the area, which is about double the size higher pressures, or locations more exposed to accidental contact with foreign objects, it has answered the purpose admirably and furnishes all necessary protection against leakage and against accidental contact. It has an additional insulation from the pole or ground in its support, which is made of glass or one of the so-called compounds, the latter being especially desirable on curves or other points where there is likelihood

AN ELECTRIC STREET RAILWAY AT BASEL, SWITZERLAND, SHOWING METHOD OF SUPPORTING THE OVERHEAD WIRES BY MEANS OF HOUSE ROSETTES. INSTALLED BY MESSRS. SIEMENS & HALSKE, BERLIN

of a strain too severe for the strength of glass.

For suburban work in the open country bare feeder wire is being adopted, as its use is a source of no greater danger than the bare trolley wire parallel to it, providing no higher voltage is employed. The remarkable development of suburban lines of thirty or forty miles in length has necessitated the use of a higher pressure in transmitting the electrical energy, the cost of copper under the old 500-volt system often being prohibitive on such long lines. In such cases use is made of an alternating current which can readily be transformed to any required voltage, and at the higher voltage the necessary power can be conveyed the greater distance without the large investment for copper, which would be required with the use of the lower pressure of 500 volts.

At suitable points along the line, a few miles apart, transformer stations are installed, which first reduce the voltage from the line pressure to one more easily controlled, and then convert it to a direct current by a rotary transformer, so-called, which is practically an alternating current motor driving a direct current generator, the two machines, however, being combined in one. This delivers the direct current at 500 volts to the trolley wire, or to supplementary feeders, which, in turn, supply the trolley wire.

These changes are necessitated by the fact that the alternating current

can be readily changed from a low to a high voltage, or *vice versa*, by a transformer consisting of coils of insulated wires. These transformers have no moving parts, require almost no attendance and involve but a small loss of power. The alternating current is not, however, at present suitable for use in a street railway motor, and must be changed to a direct current. The voltage of the direct current cannot be readily and economically changed, and the combination of the two systems is, therefore, made necessary.

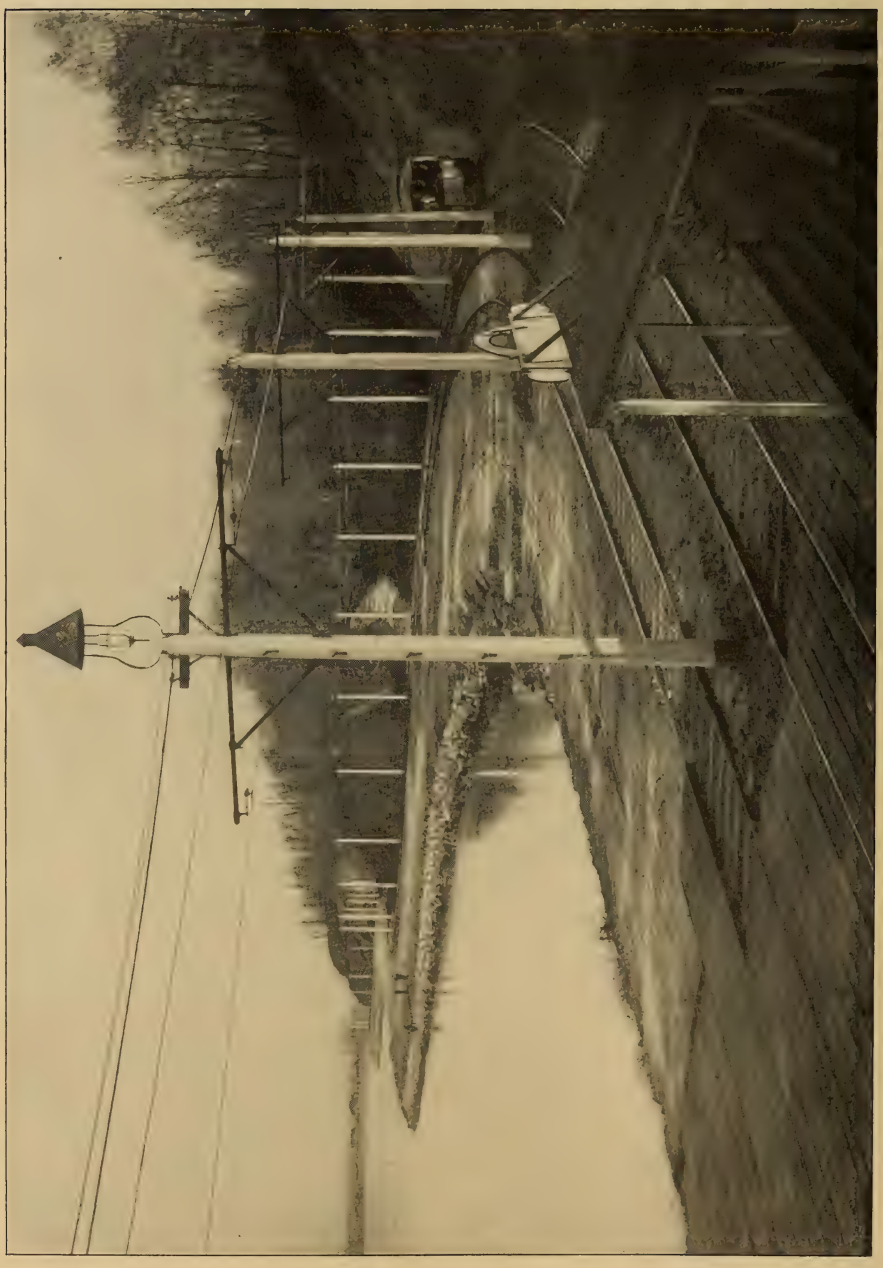
Even at the high voltages used on systems of this kind, bare feeder wires are used in the open country, special care being taken to secure the greatest strength and permanence of the supporting structure, the wire being supplied with an insulating covering in small towns where additional precautions are necessary.

For such high-potential lines porcelain insulators are usually considered indispensable, although the frequent practice in the western part of the United States on power transmission lines which are quite similar in their form and purpose, is to use glass insulators. In such cases the electrical and mechanical strength of the insulator is all-important, as it forms the only protection, the wooden pole and the cross-arm, which would in themselves form a fair insulation for lower voltage, offering little obstruction to the current of very high tension. In fact, a wire carrying a voltage of 10,000 will speedily burn off a cross-arm with which it comes in contact.

The erection of feeder wire has few difficulties other than those caused by its weight and unwieldiness. An approved method is to put the reel on a stand where it will revolve freely and attach to the end of the wire a rope,

TWO RAILROADS OCCUPYING THE SAME TRACKS, BUT USING DIFFERENT TROLLEY WIRES

A SUBURBAN ROAD BUILT IN 1892



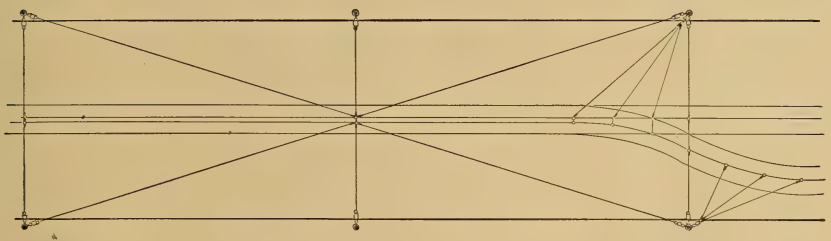
A MODERN HIGH CLASS ROAD RUNNING TO A PLEASURE RESORT. TYPICAL AMERICAN CONSTRUCTION

which has been threaded over the cross-arms in the proper location. A set of temporary rollers on top of the cross-arms protects the insulation from abrasion and facilitates pulling up the wire, after which it is made fast and tied into the insulators with short tie wires. Each and is cleaned of insulation and attached to the end of the next section by a sleeve, the whole being soldered firmly together and wrapped with an insulating tape.

In erecting either trolley or feeder wire the use of a locomotive, where conditions permit it, facilitates the operation greatly. A locomotive with two or three cars, the forward one carrying a reel of wire and the rear one a tower, will move along slowly and steadily, the temporary attachments to span wires being made without stopping the train. A skillful locomotive engineer soon learns to handle the erecting train with great certainty and skill, and the resulting economy and speed of this method of wire erection are remarkable.

Special conditions frequently arise in overhead construction, and the solution of the individual problems must depend on the resourcefulness of the engineer in charge. At drawbridges, for example, the feeder wires must be carried under the bed of the river in submarine cables to prevent the interruption of the circuit and the shutting down of that part of the line beyond the bridge when the draw is open. When the draw is closed, a switch drops into place to make the trolley wire on the bridge alive, and plates of copper or brass, with edges turned down, are attached to the trolley wire on the shore and on the bridge, by which the trolley wheel is guided to the wire on the draw.

On the New York and Brooklyn suspension bridge the expansion and contraction, due to changes in temperature, must be provided for with the trolley wires as well as with the rails. The trolley wire is cut at the proper place and both ends are firmly anchored. A brass or copper sleeve, or pipe, is passed over the end of one trolley wire at the cut and is fastened to it; the other wire is put loosely in the tube and slides as the expansion and contraction occur without interrupting the mechanical continuity of the wires. Other special devices must be arranged for other unusual and local conditions.



DOUBLE TROLLEY OVER SINGLE TRACK WITH TURNOUT, SHOWING METHOD OF PULLING OFF WIRE AT TURNOUT, AND ANCHORING

In America the development of overhead construction has been in the direction of securing lightness, strength and effectiveness at low cost, and ornamentation has not been sought. In the United Kingdom and on the European continent, however, fancy brackets, scrolls, and ornamental castings have been very largely used, and this is the essential difference between the practice on the two sides of the Atlantic. American electric railway practice has, indeed, gone so far ahead of the European in the design of the overhead structure, as in all the other essentials in this branch, that European nations are either pur-

chasing their material in America or are following American design closely; consequently there are comparatively few points of contrast.

There is, however, one feature of European construction which in many cases could be followed to advantage in America, namely, the attachment of the span wires directly to buildings on narrow streets by the so-called "rosette" construction, thus avoiding the necessity for poles where there is little room for them. On any street where the distance between building faces is less than 40 feet, or where the buildings are practically continuous, this style of construction would be an advantage, and, by the use of proper insulators, it would be absolutely safe.

It was the practice in the early days of electric railways to string a galvanised iron guard wire above the trolley wire to prevent falling electric light or telephone wires from coming in contact with it. But the danger of the guard wire itself breaking and causing crosses has led to the abandonment of this practice. Even on transmission lines, where the guard wire is barbed to furnish protection against lighting, it has been found to do more harm than good, and on the Buffalo-Niagara Falls transmission line the three lines of barbed wire originally put up have been taken down, with the result of very greatly lessening the number of interruptions on to the service line due to crosses and grounds, and so far no bad results have followed the removal of this form of lightning protection.

While track bonding is not, strictly speaking, a part of the overhead construction, the return half of the electric circuit deserves more attention than it has usually received in the past. An adaptation of Thompson's law for the most economical distribution of copper in a circuit, providing for the balancing of interest on the investment for copper against the loss of power in transmission due to electrical resistance, will show that the resistance of the return circuit should, with present prices of wire and bonds, be approximately one-half the resistance of the overhead circuit. To secure this result, bonds should be put in until the conductivity of the track is practically equal to the conductivity of the rail throughout its length. Experience shows that a short copper bond, located under the splice bar, or in the foot of the rail, is the most reliable method of securing this result. A copper bond, long enough to reach around the splice bar, is not only more expensive and must be larger in cross-section to keep the track resistance down, but is liable to loss from theft, particularly on lines running through the country, on tee-rail construction where the bond is entirely exposed. It has been found in some cases that sections even of live trolley wire have been cut down and carried off by thieves, and anything so close to the ground and as conveniently stolen as bonds must be protected.

THE DEVELOPMENT OF THE MODERN ELECTRIC RAILWAY MOTOR

By Dr. Cary T. Hutchinson

ALL the early work in the application of electric motors to tramcars involved either the idea of separate motor cars, or mounting the motor upon the platform. In no case in the very early work in this field was it clearly understood that an essential condition for the success of electric traction was that each car must be an independently driven unit, and that the motors must be placed beneath the car body, and must be positively geared to the axles.

It is not altogether clear who was the first to recognise these necessary conditions. The first motor cars of Edison, Field, Daft, Van Depoele and others all had the motors mounted on the car platforms or in the car, and connected to the car axles by means of belts, chains, or other flexible (as distinguished from positive) gearing. Under these conditions there was no reason that the form of motor should depart in any way from the form of generators at that time known, and, as a matter of fact, the same machines were used, the only difference being in the sizes.

One of the first, if not the first inventor, to recognise the necessity for maintaining perfect alignment between the driven axle and the axle of the armature, was Wellington Adams. His object was to provide an arrangement

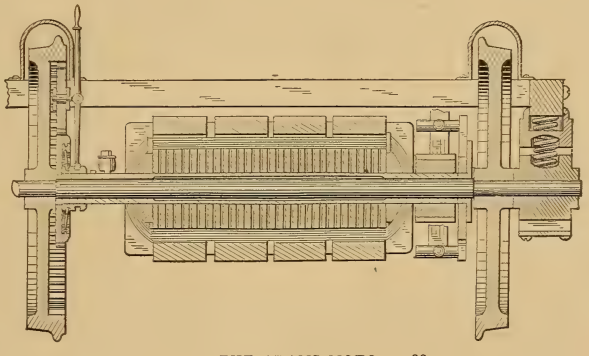


FIG. 1.—THE ADAMS MOTOR, 1884

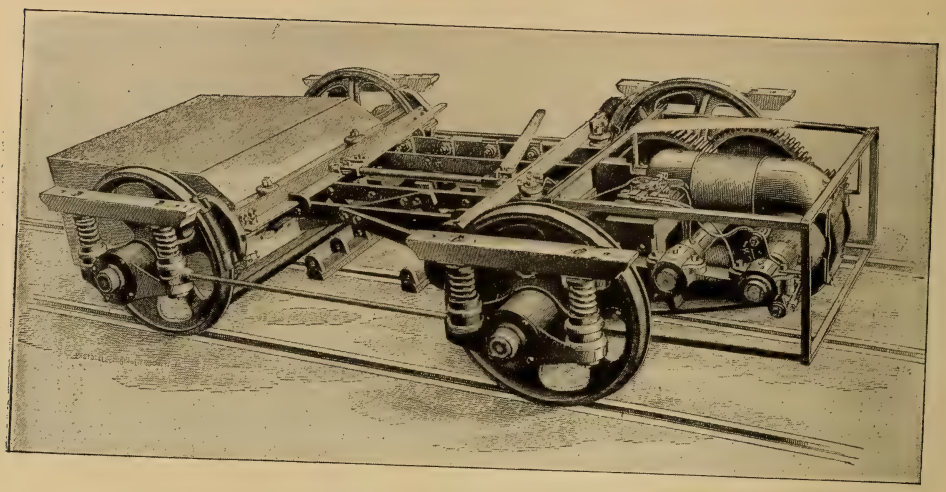
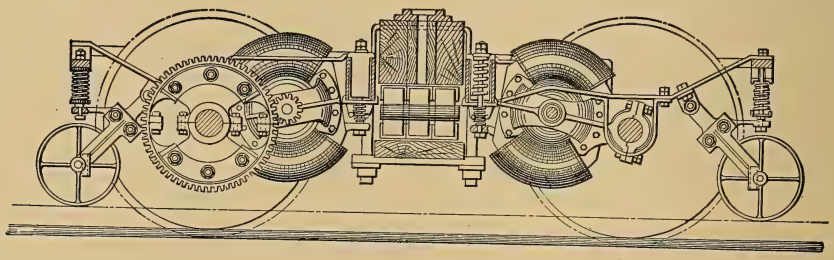
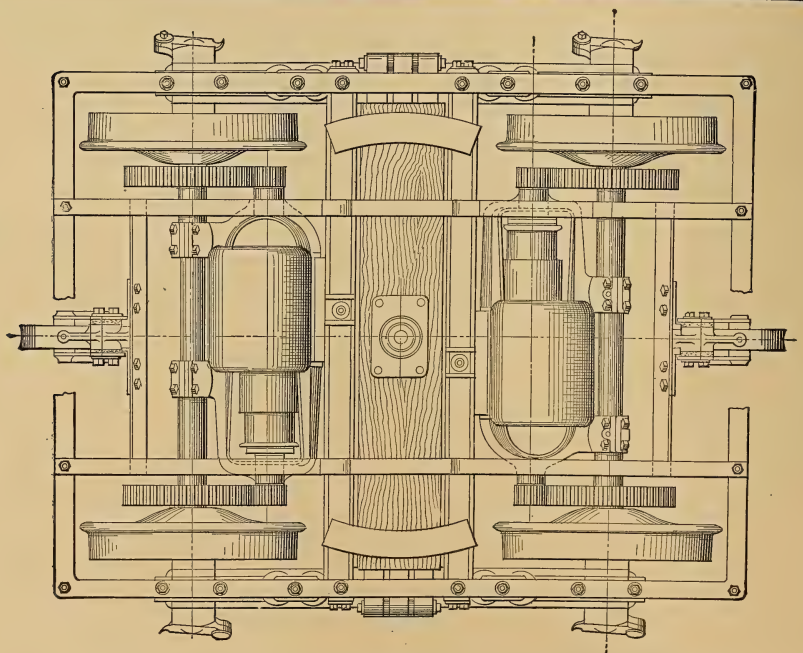


FIG. 2.—DOUBLE-MOTOR BENTLEY-KNIGHT TRUCK, 1884





FIGS. 3 AND 4.—SECTIONAL ELEVATION AND PLAN OF SPRAGUE'S ORIGINAL ELEVATED RAILWAY MOTOR, 1883-86

by which "the field and rotating armature of the electric motor and the gearing or transmitting device through which motion is communicated from the armature to the wheels of the car or vehicle can be supported in such a manner as to be independent of the body of the car, with a view to permitting the latter to move freely without disturbing the relations of the motor and transmitting device to the driven wheel or wheels." However, the Adams patents were so drawn that they were held not to cover the subject matter clearly, and the company owning them never put its apparatus into practical use. Hence, Adams's part in the actual development of the tram-car motor was a very small one, although he clearly foresaw some of the essential facts involved.

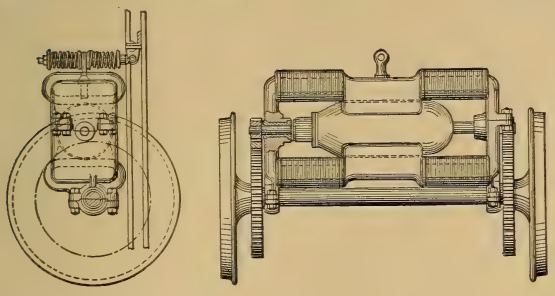


FIG. 5.—THE FIRST TRAM-CAR MOTOR BUILT BY SPRAGUE, 1886

Among the earliest inventors to put the motor under the car body were Messrs. Bentley and Knight. Their work was in the direction of an adaptation of motors to tram-cars, as distinguished from locomotives, or separate motor cars. The Cleveland road, in the United States, operated in 1884 by the Bentley-Knight Company, employed motor cars with the motors under the car body and supported from it; but the connection to the driven axles was made by means of wire cables. Thus, Bentley and Knight, while realising one of the essential features necessary to the solution of this problem, did not at that time grasp the importance of the other,—positive gearing.

The first one to embody both of these necessary conditions in one apparatus was Frank J. Sprague. The first Sprague road, at St. Joseph, Mo., did not begin operation until the latter part of 1887, and the Richmond road, regularly, until February, 1888; yet all the ideas involved in the Sprague method of centering the motor on the car axle, supporting it flexibly from an independent car truck, gearing direct with a single reduction, and using but one set of brushes, are embodied in the motors used in his tests on the New York elevated railways, illustrated in Figs. 3 and 4. Sprague's first tram-car motor, shown in Fig. 5, built in 1886 for use on a storage battery car in Philadelphia, shows the same features, except that the motors were suspended from the car frame instead of an independent truck. The motors shown in Fig. 6 were designed by Sprague in 1886 for a locomotive-car for experimental use on the New York elevated railways, but were never completed.

The success of the Richmond road practically settled the question that tramway motors must be placed under the car and must have positive gearing. At this point, then, the development of the motor *per se* begins. This development is a long series of adaptations to the various exigencies of electric traction. The early motors were the then

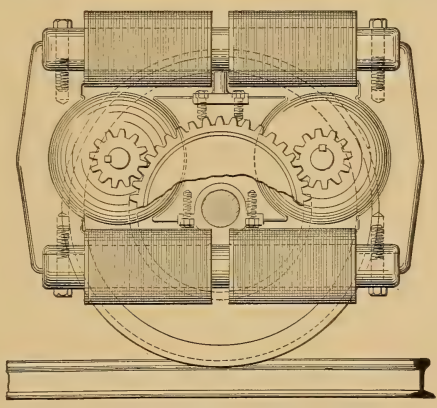


FIG. 6.—SPRAGUE DOUBLE ARMATURE MOTOR DESIGNED IN 1886

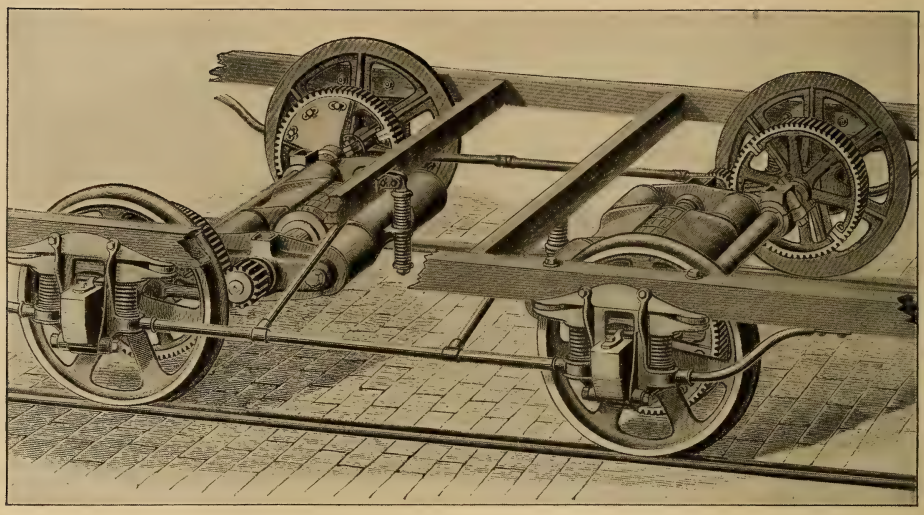


FIG. 7.—SPRAGUE NO. 5 SINGLE-REDUCTION MOTOR. RICHMOND TYPE

current form of dynamo, with such changes as were necessary to adapt them to the position under the car body. They were all of the two-pole, horse-shoe type, with the field not concentric with the armature. This is the type of the regular early Sprague, Westinghouse, and Thomson-Houston motors. This form is not compact, and is greatly exposed to water and to accidental damage. The growth has been from this simple, two-pole, open form of motor, to the four-pole, enclosed, concentric type. The development has been a steady one in the direction to afford the greatest protection to the motor from damage from the outside, and the type of the present day is, to all intents and purposes, perfectly protected from such damage.

The tram-car motor is now, without exception, single reduction, the ratio between speed of motor and the speed of the car axle varying from 5 to 3. Singularly enough, the first motors used by Sprague on the Richmond road were

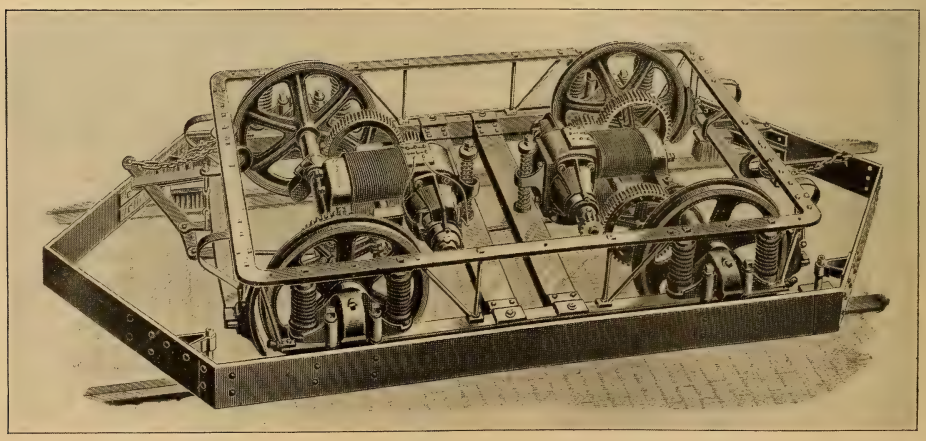


FIG. 9.—SPRAGUE NO. 6 MOTOR MOUNTED ON INDEPENDENT TRUCK, 1888. THE FIRST SUCCESSFUL ELECTRIC TRAM-CAR MOTOR

also single-reduction motors, but it was soon found that these motors were too weak to stand the great stresses brought upon them by the heavy grades and the starting of the cars. Hence, a change was made to double reduction. Fig. 8

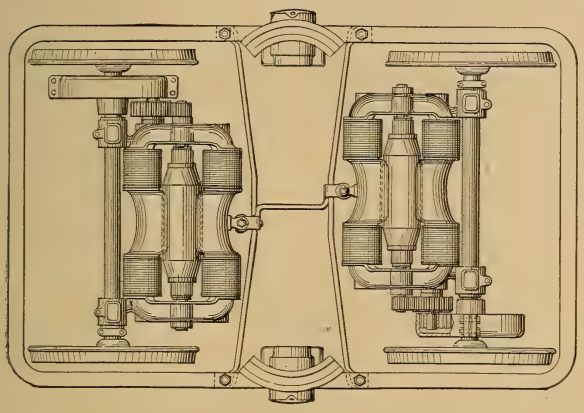


FIG. 8.—SPRAGUE'S ORIGINAL RICHMOND MOTOR CHANGED TO DOUBLE REDUCTION

shows the first Richmond motor, known as the Sprague No. 5, after it had been changed from the single-reduction to the double-reduction gearing. Here an internal gear is used. From this time up to 1890 the double-reduction was universal.

The first single-reduction motors were brought out in 1890, and almost simultaneously with them the gearless appeared, destined to a very short life. Much of the trouble with motor equipments in the early days was caused by gearing, and it was mainly for this reason that the gearless motor, when first introduced, was received with enthusiasm. Managers were eager to take up any means of escape from the constant troubles caused by double gears. The elimination of the high speed gears, however, has so greatly reduced these troubles, that there is no present field for the gearless motor.

The matter of gearing was of such importance that for the first three or four years, say, up to 1893, all sorts of gears were patented and tried, with the hope of discovering some form that would give the high gearing ratio desired and at the same time be free from the objections that had developed from the double spur gears. Among the different forms tried were chains, bevels, wire ropes, worms and others. None of these proved satisfactory. Although several eliminated many of the troubles of spur gears, other difficulties were introduced that more than offset the gain; hence none has survived. It is interesting, however, to note that as late as 1891 the General Electric Company, of New York, developed and experimented with an equipment involving chain gearing and idler pulleys. This, however, was never put into operation.

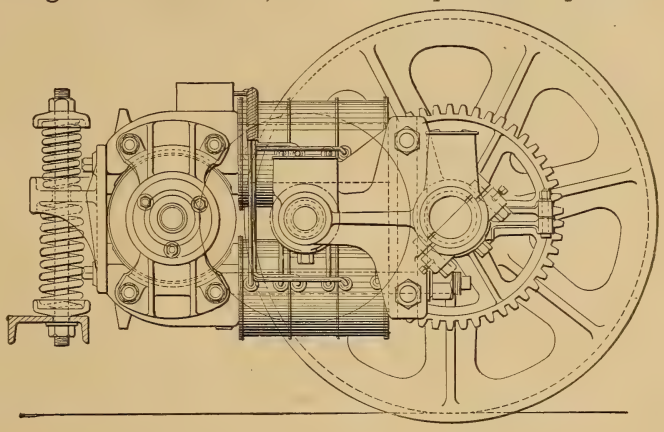


FIG. 10.—THE SPRAGUE NO. 6 MOTOR

A marked feature in the development of the tram-car motor has been the regular increase in the power of the motor. This is due both to the fact that early motors were too small for the work demanded of them, and that the work has been greatly increased. The Sprague No. 5 motor was rated at 7½

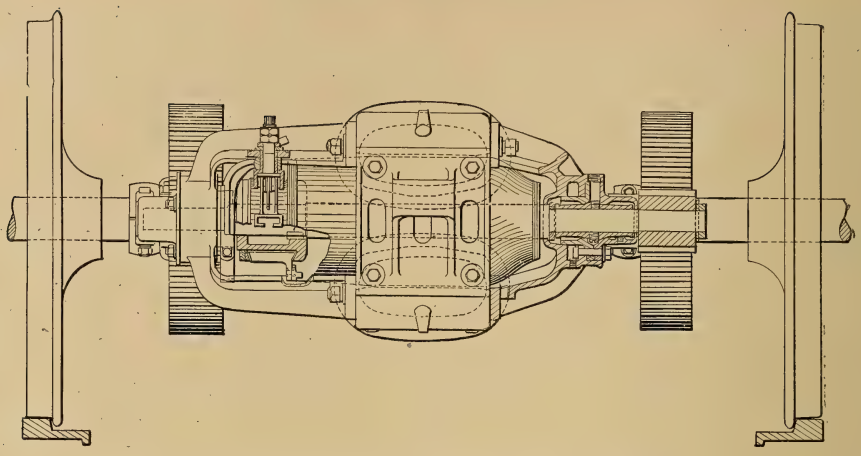


FIG. 11.—END VIEW OF THE SPRAGUE NO. 6 MOTOR

H. P. There were two motors to the car, making the equipment nominally 15 H. P. These motors had sufficient torque to drive a 16-foot loaded car up a 10 per cent. grade, the total weight of car and passengers being, approximately, 7.5 tons. At the present day an ordinary equipment consists of two 20 or 25 H. P. motors. The weight and size of the cars has been greatly increased, and the traffic requires much greater power on account of the rapid schedules now demanded.

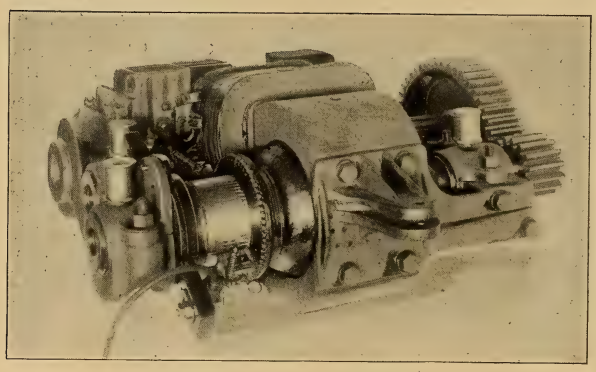


FIG. 12.—THE FIRST THOMSON-HOUSTON MOTOR, *F*-30

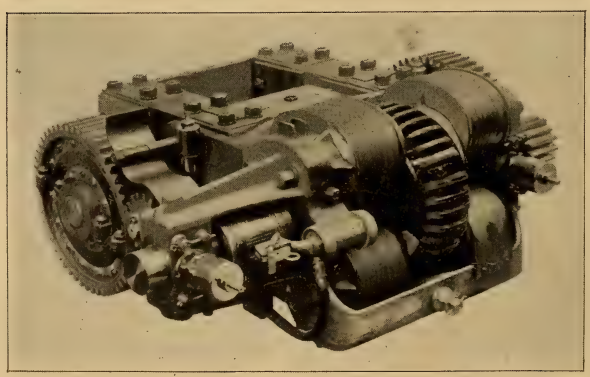


FIG. 13.—SHORT'S DOUBLE-REDUCTION MOTOR, 1890

Starting, then, with the Bentley-Knight motor as the first step in the actual modern development of the tram-car motor, the second step was the Sprague motor, shown in Figs. 3 and 4. Four of these motors were built for experiment on the Thirty-fourth Street branch of the New York Elevated Road in the winter of 1885-6. They were spring suspended, axle centered, and positively geared with one reduction, which methods have become universal.

The next Sprague motor was built in 1886, to be used, as already mentioned, on a storage battery car in Philadelphia. As shown in Fig. 5, page 339 it was centered on the axle and was flexibly supported from the car frame. This was

the first tram-car motor built by Sprague. It had four field coils, two salient poles, and one commutator. Unfortunately, no technical data of this motor are now extant. Its weight was approximately 1200 pounds, and the gearing ratio, about 5 to 1.

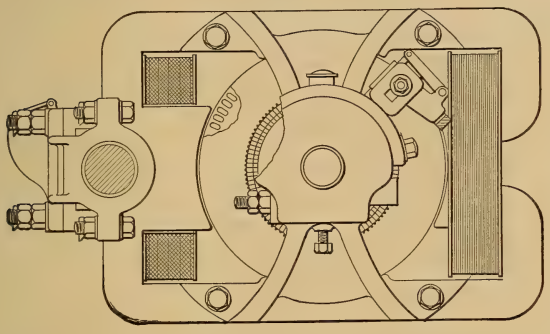


FIG. 14.—THE WENSTROM SINGLE-REDUCTION MOTOR, 1890

The motor was a slight departure from the generators of that time, and the magnetic circuit was extremely bad, judged by present standards.

The second Sprague tramway motor is shown in Fig. 7, mounted in place on a car frame. This is the original No. 5 motor, with single gearing, as used at Richmond, Va. It differs very slightly from the No. 4 in general design. The chief point of departure is the use of two commutators instead of one, with a fixed brush at the top of each commutator. The object of this construction was to make both brushes accessible.

The next step in the development is shown in Fig. 8, which illustrates the Sprague No. 5 motor with the first change to double gearing. The change to this form from the motor shown in Fig. 7 is made by the addition of a stud on the field magnet frame, on which was mounted an intermediate gear and pinion, the pinion meshing with an internal gear fixed on the axle. No alteration was made by this change in the distance between the centres of the armature shaft and driven axle. This is the motor that was used on the Richmond road until the advent of the No. 6.

A short experience with this motor proved that it was too weak, both mechanically and electrically, for the duty demanded of it. As a consequence, the Sprague No. 6 motor, shown in Fig. 9, mounted on the truck, was brought out at the end of 1888. This became the standard Sprague motor, and nearly 4000 of this type were built by the Sprague and Edison General Electric companies, the latter having absorbed the former. It was the first thoroughly successful tram-car motor. A number of them are still in use in various parts of the United States.

No data can now be got at for the No. 4 motor, and comparatively little for the No. 5. Both motors employed the commutated field method of control,

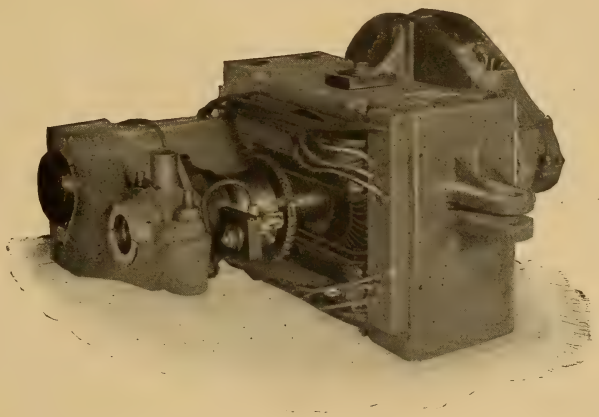


FIG. 15.—THE FIRST THOMSON-HOUSTON SINGLE-REDUCTION MOTOR, 1891

introduced by Sprague, and for a time also the series-parallel combination for the armature.

The nominal rating of the motors is 7½ H. P. at 500 volts, giving a full load current of, say, 11.2 ampères. The weight is approximately 1250 pounds, without gears; the gearing ratio, 12;

and the weight per H. P. thus is about 160 pounds, at a speed of, approximately, 1200 revolutions per minute.

The Sprague No. 6,—the standard

FIG. 16.—WESTINGHOUSE NO. 3 MOTOR, 1891

Sprague and Edison equipment up to the time of the introduction of the single-reduction motor,—was of the horse-shoe type. Figs. 10 and 11 show this motor in detail. It was practically the last of the double-reduction motors made by either the Sprague or Edison Company. One other,—the No. 8,—was brought out by the Edison General Electric Company, but was used so little that it need not be considered. It was a mere modification of the No. 6.

Shortly after the Sprague Company, the Thomson-Houston Company entered the field. This company had purchased the rights of Van Depoele and Bentley & Knight. The first motor they put on the market was the F-30, shown in Fig. 12. It was a double-reduction motor of the bi-polar type, similar in most respects to the Sprague No. 6. The armature and fields were entirely exposed. The nominal output was 15 H. P.; the armature was smooth core, drum wound; resistance of armature, 1.93 ohms, total weight of motor, without gear or gear cover, 1975 pounds; gearing ratio, 9.4; speed of motor at 25 ampères, 1000 revolutions per minute. This was the only double-reduction motor brought out by the Thomson-Houston Company, and for a year or more the fight between these two companies was represented by these motors.

In the spring of 1890 the Westinghouse Electric and Manufacturing Company, profiting by the experience of the other two companies, entered the railway field with a double-reduction motor. Shortly after, the Westinghouse Company adopted the plan of hinging the fields, and added a dust-proof gear-case,—both of them useful improvements. The motor had a capacity of 15 H. P. at 1100 revolutions per minute, the gearing ratio being

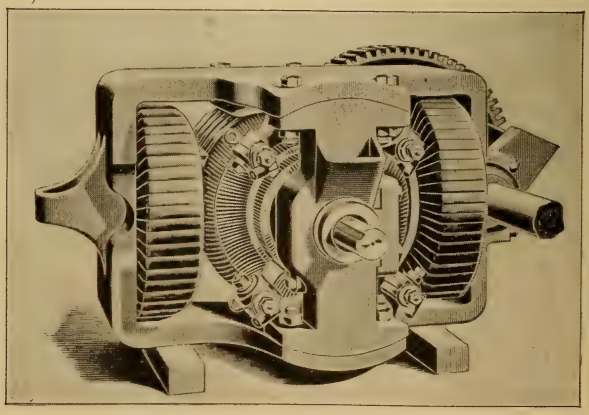


FIG. 17.—EDISON SINGLE-REDUCTION MOTOR, 1891

substantially the same as in the other two motors. It was the only double-reduction motor made by the Westinghouse Company. These three motors were all varied slightly in the proportions, windings, and gearing ratios. Changes and improvements were made in them from time to time without essentially altering their characteristics. They controlled the field until the fall of 1890, when the single-reduction motor made its first appearance.

Among the other companies that brought out double-reduction motors were the Short Company, whose motor is shown in Fig. 13, and the Detroit Electrical Works. The Short motor was of an entirely different type from the others, resembling generally the Brush arc-light generator. The armature coils were separately wound between large teeth. The magnet cores faced each other on two sides of the armature. With a motor of this kind, it was necessary to use a thrust bearing, which alone would have been sufficient to condemn the motor. As this type of motor did not persist, and has no place in the development of the present tramway motor, it is shown merely as an interesting variation from the general type.

The Detroit Electrical Works built a one-motor equipment; the first was double-reduction, with one pair of spur and one pair of bevel gears. No attempt was made to secure accurate alignment of gears; hence this equipment was not successful. The motor itself calls for no special comment, as the figure shows that it was of the usual type. Although double-reduction motors were fairly successful from an electrical point of view, as a whole, the experence with them was discouraging, owing chiefly to the endless trouble caused by the high-speed gearing. The gears were noisy, and quickly became worn,—even to a knife's edge. The high-speed gears lasted from two to four months.

The expense and trouble of replacing the gearing were very considerable, and managers of tramway systems demanded something better. As a result, nearly all the electric companies turned their attention to the problem of eliminating gears, turning to single-reduction, and two, to gearless motors.

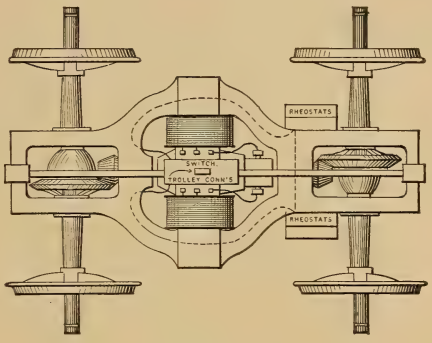


FIG. 18.—THE DETROIT PARAGON MOTOR

The first single-reduction motor,—the Wenstrom,—was exhibited in October, 1890. It was designed by H. F. Parshall, then chief engineer of the Wenstrom Company, and is shown in Fig. 14. The appearance of this motor was followed quickly by a series of single-reduction motors, the first of the

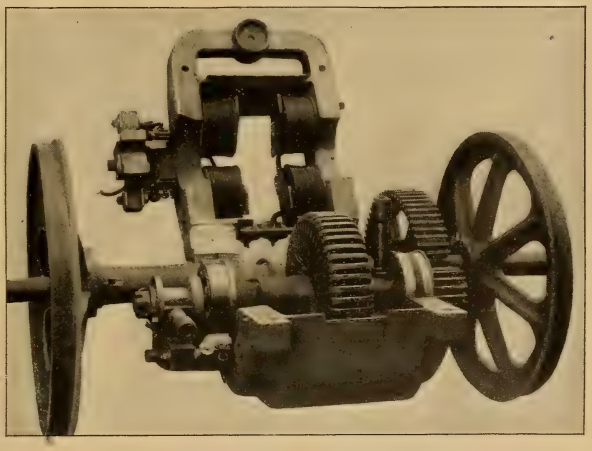


FIG. 19.—SHORT'S SINGLE-REDUCTION MOTOR, 1891

series being the Thomson-Houston design, shown in Fig. 15, brought out in February, 1891. A month or so later the Westinghouse Company brought out the motor shown in Fig. 16. The Edison Company followed with the motor shown in Fig. 17, and the Baxter, Short and Detroit companies also introduced single-reduction motors at about this period.

These motors were all multipolar and all had single-reduction gearing, but in other respects they differed materially. The first,—the Wenstrom,—had two field magnet coils placed upon the horizontal poles, the two vertical ones being

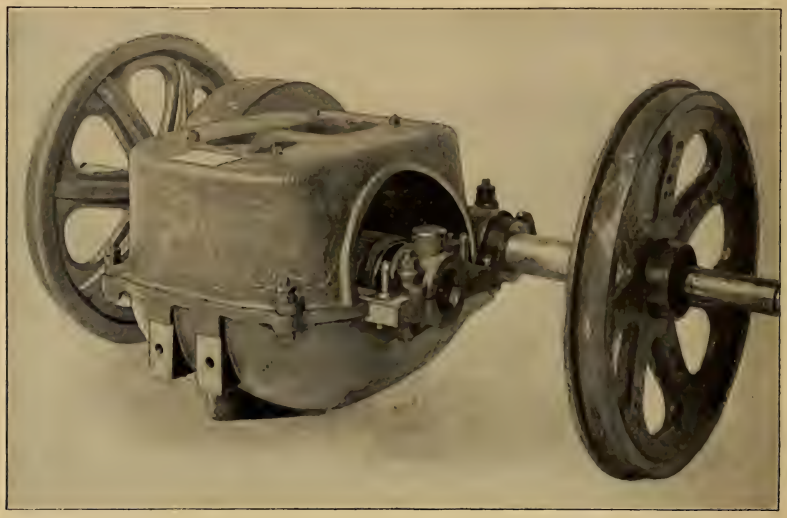


FIG. 20.—THE *W P*—30 THOMSON HOUSTON MOTOR

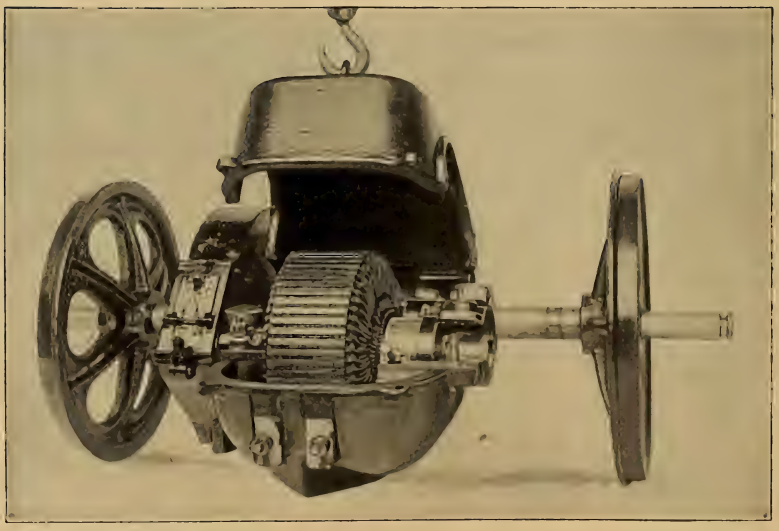


FIG. 21.—THE SAME MOTOR WITH CASE RAISED

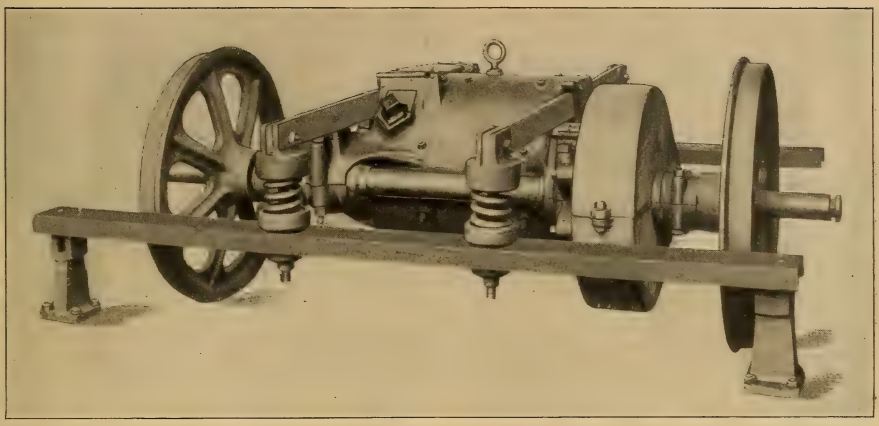


FIG. 22.—THE WESTINGHOUSE 12 *A* MOTOR WITH PARALLEL SIDE BAR SUSPENSION, 1893

consequent. The armature was perforated and drum-wound, the wires necessarily being threaded through the slots in the core. The speed was 400 revolutions, and the gearing ratio about 4. This was the first design in which the horse-shoe type was given up, and a step made toward the concentric type, now the vogue, thus making a partly iron-clad motor.

The second of this series,—the Thomson-Houston motor shown in Fig. 15, the first single-reduction motor of that company,—was a different type. The frame was an open box, and the armature and field coils were entirely exposed. The top pole piece was removable, for inspection and access to the armature. The gearing ratio was 4.8; resistance, 4.6 ohms; weight, 484 pounds; rating, 15 H. P. This was a two-pole motor. The field coils were constructed to surround the armature partly; it had a smooth core.

The Westinghouse No. 3 motor (Fig. 16),—the first single-reduction motor of that company,—shows many points of difference from the two previous motors. The field magnets are held in a rectangular frame, which contains the bearings, this frame being similar to that used in the Westinghouse double-reduction motor. The magnet frame is cylindrical, with four inwardly projecting poles, cast solid with the frame; it is divided into two sections, and hinged so as to permit inspection and removal of the armature. There are four field coils, thus avoiding consequent poles. The frame is of soft cast iron. The armature is a slotted drum, wound with machine-formed coils, connected to form a series winding; consequently only two brushes are required for the four-pole motor. Considerable improvements were made in the construction of the commutator. The gearing ratio was 3.3. The motor was fairly well enclosed by reason of its construction, and arrangements were made to close one end entirely by means of an iron plate. The weight of the motor was 2700 pounds. This motor represented

FIG. 23.—A WESTINGHOUSE 150 H. P. RAILWAY MOTOR

a long step toward the present type, and was the first in which series armature winding, four field coils, and ma-

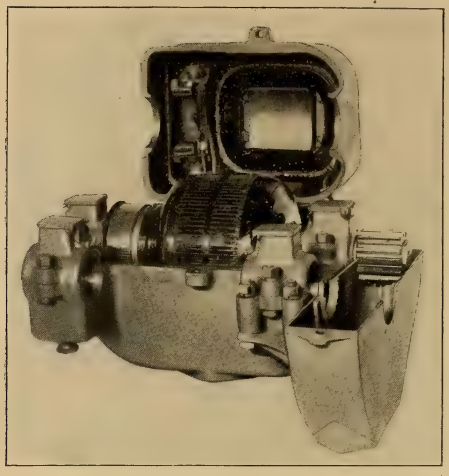


FIG. 24.—THE *G E*—800 MOTOR, 1892

chine-wound armature coils were all used. These were all points of the greatest importance, and had a strong influence on the development of the motor.

The Edison No. 10 was the first of the series of single reduction motors of this company, excepting an interesting variation to be described. It was soon succeeded by the No. 14 (Fig. 17), rated at 20 H. P.,—substantially the same motor. In general design this last motor resembled the Wenstrom. It was of the four-pole, iron-clad type. The frame was of cast steel, made in four castings, two constituting the frame proper, and the other two the detachable pole pieces. The bearings were both cast in the lower field frame, thus preserving the alignment. There were two field coils, and necessarily two consequent poles. The field coils were made of three sections, the commutated field method of control being used with these motors, following the practice of the Sprague Company.

The armature was Gramme-wound, either smooth core or slotted; gearing ratio, 5. The weight of the armature was 460 pounds; and the resistance, 0.85 ohms. The magnet coils were wound in several different ways, depending upon the service for which the motor was intended. The weight, without gears, was 1580 pounds; rating, 20 H. P. The No. 16 motor of this type was rated at 25 H P., and was of the same general design, the gearing ratio being 3.29. The weight of the motor complete, without gears, was 2270 pounds.

The other motors of this series do not differ in any general respect from these two; the only changes are those necessitated by the different capacities.

The Short single-reduction motor is shown in Fig. 19. The armature is a Paccinotti ring with Gramme winding. The core is built up by winding a ribbon of sheet steel directly on the hub. The motor frame is cast iron, and well

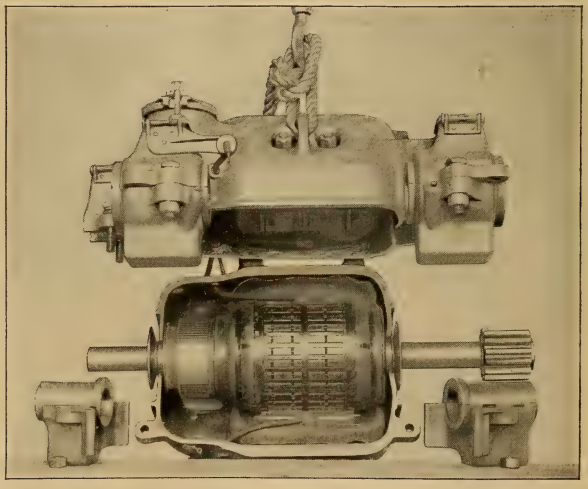


FIG. 25.—THE *G E*—52 MOTOR

enclosed. It represented a step in advance, as far as enclosing the motor is concerned, but it was not a successful type of motor.

The Detroit Electrical Works brought out an equipment differing entirely from

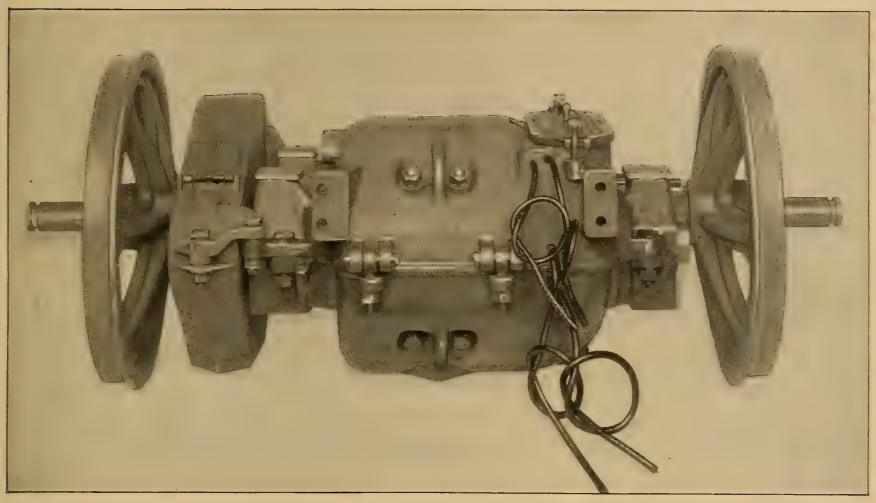


FIG. 26.—A *G E*—52 MOTOR IN ITS WORKING POSITION

any previously described. This company had entered the field early, and had passed through various stages in the development. Their double-reduction, single-motor equipment had considerable use in the western part of the United States. The single-reduction, single-motor equipment, shown in Fig. 18, involved a number of new points. The entire weight of the motor was carried on spring connections, and both axles were driven by the one motor. The connection between the gears and the armature shaft was flexible, arranged to keep the gears in alignment independent of the motion of the car axle and car frame. The motor was of the four-pole type, with two brushes, and a gearing ratio of 3. Although much was expected from this single motor equipment, it developed certain disadvantages which prevented it from coming into general use.

The experience with the *S R G* type not being satisfactory, the Thomson-Houston Company brought out the *W P* type. The *W P*—30 (Figs. 20 and 21), the first of this series,—rated at 15 H. P.,—was the first entirely self-contained motor put on the market. All the working parts were enclosed by the frame of the motor itself; hence the name *W P*, standing for water-proof.

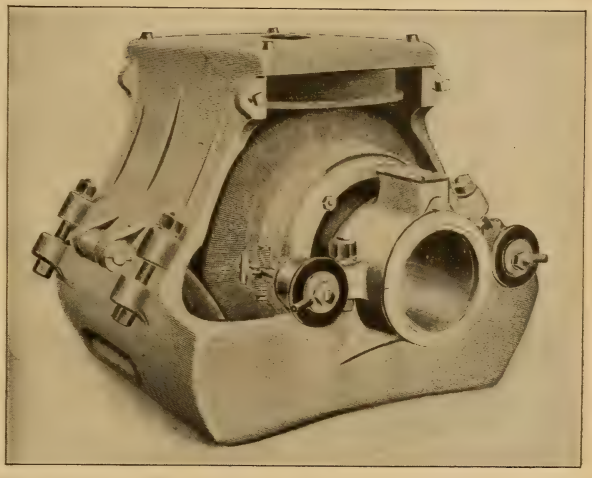


FIG. 27.—THE SHORT GEARLESS MOTOR

The frame of the motor is made in two equal parts, hinged and bolted together, so that the top half can be raised for removal and inspection of the armature. The motor has two poles with only one field coil, placed in the upper half of the frame. The armature is slotted, with a Gramme ring winding. Flat ribbon

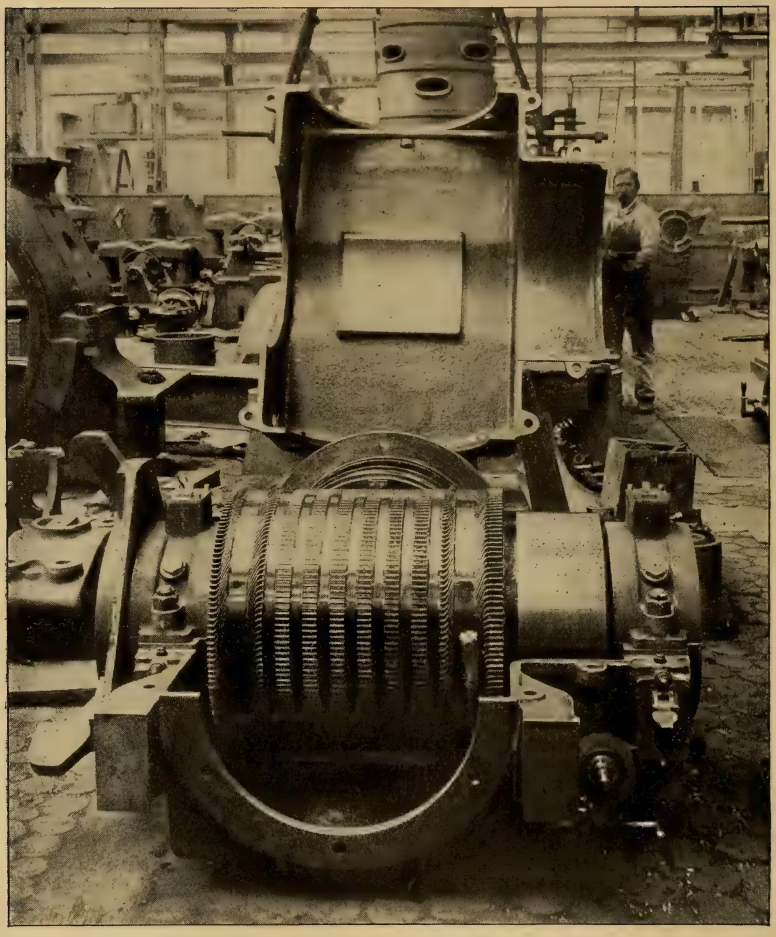


FIG. 28.—CONTINUOUS-CURRENT RAILWAY MOTOR BUILT BY MESSRS. BROWN, BOVERI & CO., OF BADEN, SWITZERLAND, FOR THE HEILMANN LOCOMOTIVE

wire is used; the gearing ratio is 4.8. This motor has several armature windings, depending upon the service. The weight of the armature is 550 pounds; total weight of motor, without gear or gear covers, 1650 pounds.

Other motors of the *WP* type were made, differing only in details, caused by different sizes. This type, although an improvement in the matter of enclosure, was distinctly a retrograde step in that it went back to the bi-polar form, and, worse yet, that only one field coil was used. It was practically impossible that a motor of this type should give good commutation. This was the last motor brought out by the Thomson-Houston Company before its consolidation with the Edison General Electric Company.

The Westinghouse Company in 1893 produced its No. 12 motor. This motor was similar, in a general way, to the No. 3, the main difference being in its higher speed. The chief mechanical difference between this and the No. 3 was the abandonment of the rectangular frame which carried the magnets. The weight was 1970 pounds, and the speed was considerably higher than that of most of the others, being 550 revolutions per minute at full load. Some-

what later, the Westinghouse Company brought out a variation of No. 12, called No. 12 *A* (Fig. 22). It was essentially the same, the main difference being that this motor was completely enclosed, thus following the example of the *W P* type. Like the previous Westinghouse motors, the slotted armature, series winding, was used. The Westinghouse Company has since brought out several other motors. The No. 38, while of the same general type, was the first in which laminated pole pieces were used. This proved to be a step of great importance, and had a marked influence on the performance of the motor. The No. 49 was of the same type as the No. 12 *A*, but was of greater capacity. A number of improvements were made in its design, reducing the weight in spite of the greater capacity.

The combination in the United States of the Thomson-Houston, the Edison General Electric, the Brush and the Short companies in 1893, forming the General Electric Company, of New York, soon brought about a practical abandonment of the Sprague, the Short, the Edison No. 14, and the *W P* types. These motors did not go out of use immediately, but were gradually supplanted by the new type of motors introduced by the General Electric Company. This series, known as the *GE* type, was brought out in 1892. The first *GE* motors were designed as *GE*—800, *GE*—1000, etc., the number following the letters indicating the draw-bar pull of one motor at full load, mounted on 33-inch car wheels. This

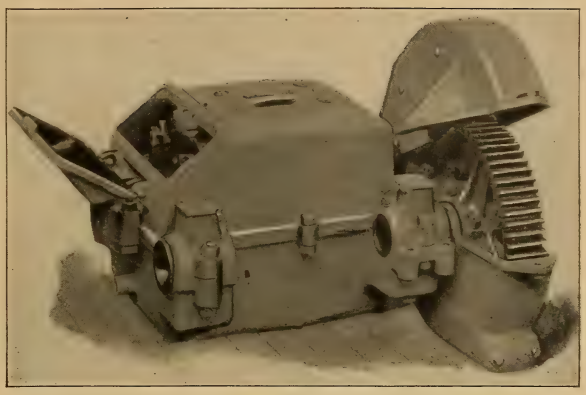


FIG. 29.—MOTOR MADE BY THE BRUSH ELECTRICAL ENGINEERING CO., LTD., LONDON

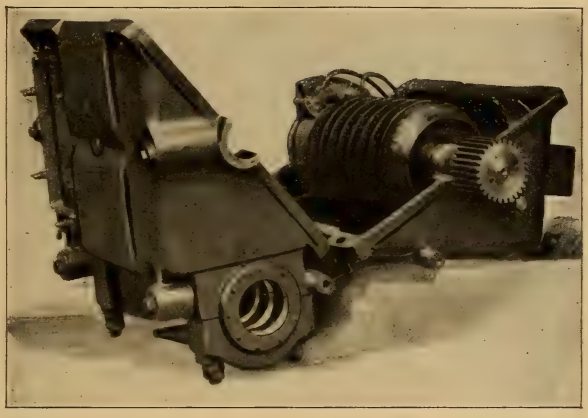


FIG. 30.—MOTOR MADE BY MESSRS. SIEMENS & HALSKE, BERLIN

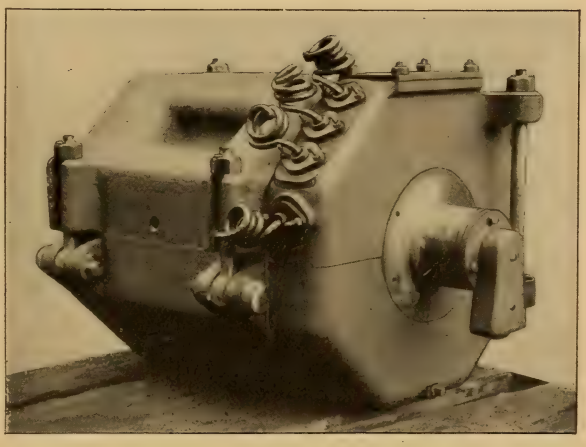


FIG. 31.—MOTOR MADE BY MESSRS. CROMPTON & CO., LTD., LONDON

was supposed to be an improvement in the method of rating motors, but it soon fell into disuse; the later motors of the *GE* type have arbitrary designations,—for instance, *GE*—52.

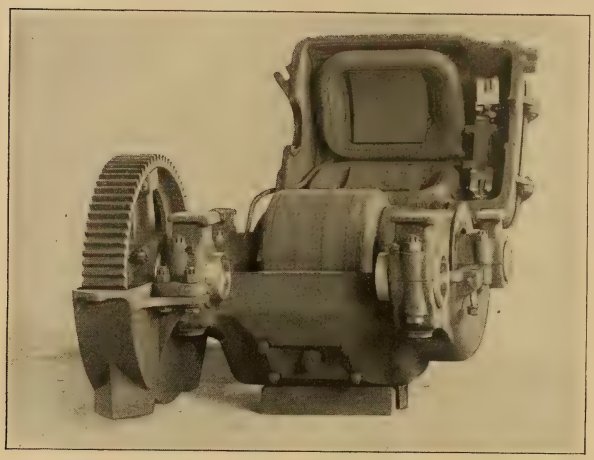


FIG. 32.—RAILWAY MOTOR MADE BY THE ELEKTRICITÄTS-AKTIENGESELLSCHAFT, NURNBERG, GERMANY

The *GE*—800 frame consists of two steel castings, hinged at one end, and arranged so that either the top or bottom half can be dropped. There are four poles, with two field coils. The armature is slotted, and uses the Eickemeyer coil winding, this being the first instance, aside from its use by Eickemeyer himself, of this type of winding.

The *GE*—800 armature winding is connected in series, thus following the example set by the Westinghouse Company. The *GE*—800 was followed by the *GE*—1000, *GE*—1200, and *GE*—2000, these motors being of the same general type, differing in size.

The series was followed by the latest motor of the General Electric Company,—the *GE*—51, *GE*—52, and *GE*—57. The changes in this last type are chiefly those of detail, with the exception of the adoption of laminated pole pieces and the use of four field coils. The improvements have been in detail of design, particularly reduction of weight for given output, and improvement of the commutation, and less heating. This applies to all the modern motors, particularly in regard to commutation. It is possible now to put from two to four times the full load current through one of these motors without sparking.

The Walker Company entered the railway field several years ago, with a motor very closely resembling the standard motors which have been described. In this motor a number of minor improvements were made, particularly in regard to the suspension and means for getting at it. The motor does not differ in any general respect from the Westinghouse and General Electric motors of the time.

The troubles with the early double-reduction gearings, as has been said, caused the manufacturing companies to try all possible means to eliminate them. The single-reduction motor has proved successful, but when it was

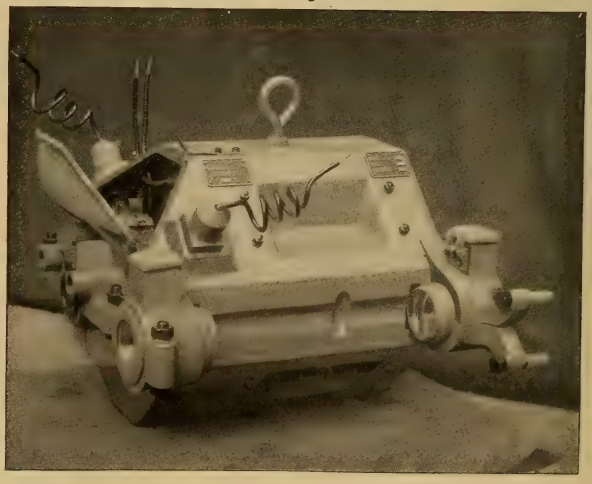


FIG. 33.—A MOTOR MADE BY MESSRS. GANZ AND CO., BUDA-PESTH

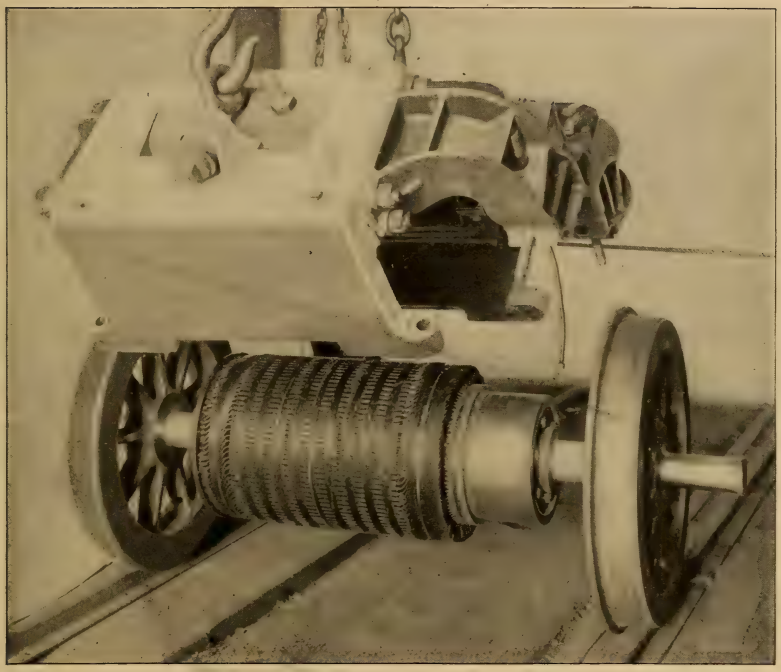


FIG. 34.—ONE OF THE GEARLESS MOTORS BUILT FOR THE CITY & SOUTH LONDON RAILWAY BY THE THAMES IRONWORKS & SHIPBUILDING CO., LTD., LONDON

first introduced two of the companies went even further, producing gearless motors. The first Short gearless motor was of the same general type as the Short single-reduction motor. This type, however, was not successful. After making one or two experiments, the Short Company finally brought out the motor shown in Fig. 27. This was a 6-pole motor, with three field coils, and therefore three consequent poles, and was connected to the axles with a flexible coupling. The total weight of the motor was 2300 pounds.

The Westinghouse Company about the same time that it introduced the single-reduction motor brought out a gearless motor. This motor was completely iron-clad, and the armature was built upon the car axle, thus differing from the arrangement of the Short motor. It was rated at 20 H. P., and an efficiency of 90 per cent. was claimed for it.

These two motors are interesting chiefly as illustrating the very serious

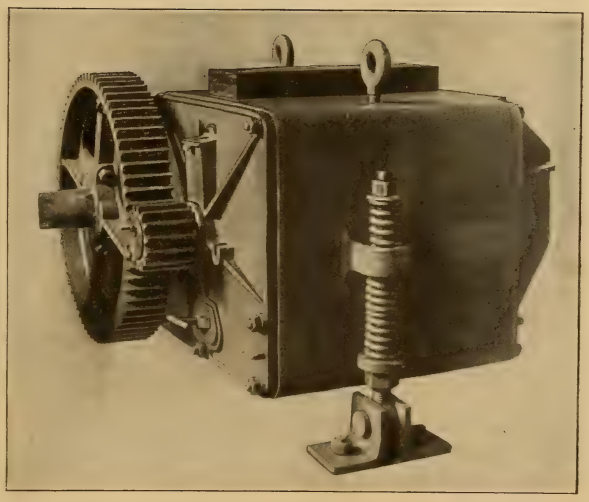


FIG. 35.—RAILWAY MOTOR MADE BY THE ALLGEMEINE ELEKTRICITÆTS-GESELLSCHAFT, BERLIN

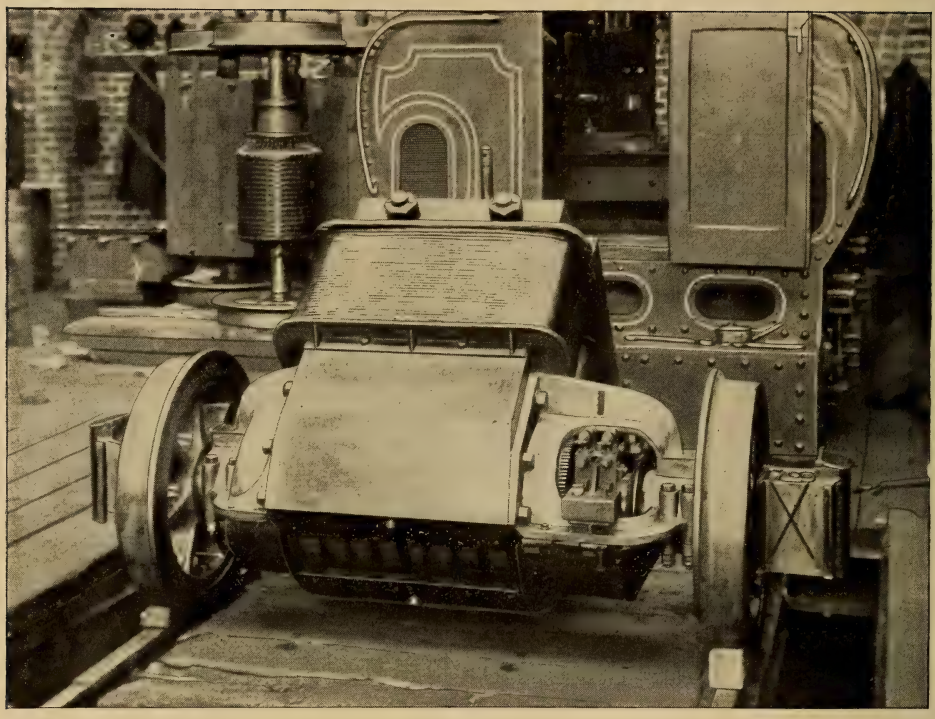


FIG. 36.—A MOTOR FOR ONE OF THE LOCOMOTIVES USED ON THE CITY & SOUTH LONDON UNDERGROUND RAILWAY, MADE BY MESSRS. SIEMENS BROS. & CO., LTD.

character of the gearing trouble. The motors themselves were too heavy and costly to come into general use, in the face of the single-reduction type. Had the single-reduction gearing caused as much trouble as the double reduction, there is little doubt that the gearless motor would have been the final type.

One other gearless motor, built on an entirely different plan, came into some use,—the Eickemeyer-Field. This was mounted between the axles, driving the car wheels by means of a crank disc and connecting rod. It succeeded a single-reduction equipment of the same general type. The motor had a nominal output of 35 H. P. and made 150 revolutions at full load; the weight, including the wheels, was 9000 pounds.

The motors described are all series-wound. Various attempts have been made to use shunt-wound motors, but they have been uniformly unsuccessful for many reasons, one of the most important being the fact that in them the field circuit is interrupted by reason of the bad contact between the wheel and the rail.

One of the most interesting of these attempts to use a shunt motor was made by the Edison General Electric Company in 1891. The motor was to be called the "New Edison Street Car Motor No. 6." In addition to the shunt field, this motor also embodied an attempt to get rid of the positive gearing between the motor car and axle, substituting for it sprocket wheels with chains, supported by idler pulleys. This motor is rather interesting as an illustration of the extremes to which the manufacturing companies went in the attempt to eliminate the troubles caused by spur gearing. It did not, however, get beyond the shops of the company.

The several makers have produced a number of motors of the same general type, but of different capacities. Motors are now made up to 150 or 200 nominal horse-power. They differ

from the motors described mainly in dimensions, and, hence, are of no importance in connection with the development of types.

It is only recently that any definite standard of rating has been adopted for tram-car motors. In the early stages of the art, motors were designated approximately by the maximum horse-power they could exert for a short time, heating being practically ignored. Now, a definite rating, based on a temperature elevation of 75° C. for one hour's run at full load, has been adopted, and motors are rated more closely than they formerly were. This difference in rating increases the disparity in weights per horse-power and weight for unit torque, since present ratings are much closer to facts than were the earlier ones.

The most important features in the development of the modern tram-car motor are, then:—

The flexible suspension by which the motor is centered on the axle; the use of fixed brushes; and the change from the open, horse-shoe type to the closed, concentric type. This change, as the cuts show, has been a gradual growth, all of the various companies having a part in the development.

The change from the old style, smooth-core, hand-wound armature, with one coil per commutator bar, to the present deeply slotted, drum-wound type, with machine-made coils, series armature connections having two brushes to the motor regardless of the number of poles, and with two or more coils per commutator bar. The series connection,—a most important step in the growth,—is due to the Westinghouse Company. The first use of machine-wound armature coils, made on forms, the coils being identical, was by Eickemeyer. Sprague, in 1889, saw the marked advantages of this form of winding, and induced the Edison General Electric Company to take it up. This or other machine form windings adapted to 4-pole motors have since been very generally used.

The change from double-reduction to single-reduction gearing. This step was made almost simultaneously by all the companies. The need for it was so clear that all were working in that direction. The Wenstrom motor, however, was the first machine exhibited.

The introduction of laminated pole pieces. This is due to the Westinghouse Company and brought about great improvement in the commutation of motors. The introduction of the hinged magnet frame is also due to the Westinghouse Company. This made access to the armature for removal and inspection easier than it had been.

The introduction of cast steel has been the means of greatly reducing the weight of motors, and has made possible a single-reduction motor weighing no more than the old double-reduction motors.

Armature diameters have been much decreased relatively, thus reducing the inertia of the moving parts. The efficiency of the motors at low loads has also been much increased, producing greater all-day economy, as the motors necessarily run at very low average load.

The design of the armature and field windings has been greatly improved, both with regard to insulation and the amount of copper used, and, as a consequence, the old trouble of burnt-out field coils is now comparatively rare.

The improvement in the commutation has been one of the most striking developments. The earlier type of motors sparked viciously at nearly all loads. The use of fixed, radial carbon brushes helped to avoid this trouble, but a better knowledge of the principles of designs has done more. The modern tram-car motor, with commutator in fair condition, is practically sparkless at any current that can be put through it.

These are the main steps in the production of the present motor. Many others might be named,—chiefly mechanical features, which have been of great importance from the managers' point of view; but a detailed treatment of all these points is not now feasible.

No reference has been made to the very early work of Field, Van Depoele, Daft, Short and others, nor to the early

European work, nor has anything been said of the later European work, since in all its essentials it corresponds to the designs shown here, and the several illustrations that are given in this article of British and Continental tram-car motors, in a measure, tell their own story. Generally speaking, the same form of motor is in use on both sides of the Atlantic, the chief difference being that in Great Britain and on the Continent they are of greater weight for the same output than in the United States.

An attempt has been made in following the development of the tram-car motor to select typical illustrations of the chief steps in the progress. Many other motors were produced by different designers, but none seemed to possess any characteristic sufficiently marked to be perpetuated in the present type of motor. Doubtless many minor improvements were due to the work of companies and inventors not mentioned, but an enumeration of all this work would be impracticable.

SOME EARLY TRACTION HISTORY

By Thorburn Reid

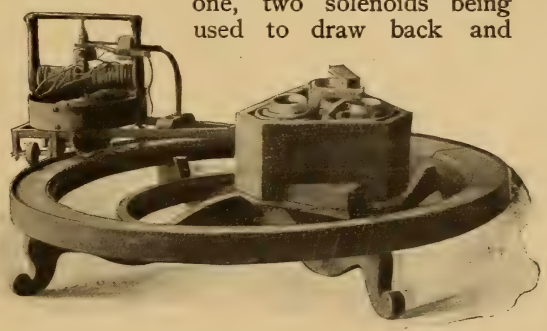
THE modern electric railway may be said to have been born in the year 1835 in the small American village of Brandon, in Vermont, with the village blacksmith, one Thomas Davenport, as sponsor. The child was weak and puny, and was destined to languish long in obscurity and neglect, passing through many vicissitudes before it finally attained the strength of vigorous development.

At that time, and for many years afterwards, the primary battery was the only available source from which electric energy could be obtained for driving motors. The initial cost of the primary battery was very high, and the cost of the chemicals consumed in it was about sixteen times that of the coal required to produce the same amount of electrical energy through the medium of the steam engine and the modern dynamo. This great expense, combined with the difficulty in handling the liquids and more or less fragile materials used in the construction of the battery, constituted an insurmountable obstacle to the commercial use of the electric motor for traction purposes.

Notwithstanding this, however, many inventors worked at the problem during the period from 1835 to about 1873, when the power-driven dynamo commenced to take such shape as to make it commercially available as a source of electrical energy for driving motors. During these years many of the details were worked out and methods employed which are still used in the best modern practice.

Following Davenport, who drove his motors with current supplied by primary batteries carried on the car, came Robert Davidson, of Aberdeen, Scotland. He built a powerful electric locomotive which made a number of trips on Scottish railways and was finally destroyed, presumably by some engineers who feared that their own machines would be superseded by the new invention. He, too, used primary batteries carried on the locomotive.

The next experiment on a large scale was made in 1850 by Prof. C. G. Page, of the Smithsonian Institution at Washington, D. C., who, like Davidson, worked at the idea of an electric locomotive. His motor was a reciprocating one, two solenoids being used to draw back and forth a soft iron piston rod, which was connected to a fly-wheel by means of a connecting rod and crank. Prof. Page tried several other motors of the same general character and suc-



DAVENPORT'S ELECTRIC RAILWAY MODEL, 1835

THE SIEMENS & HALSKE ELECTRIC RAILROAD, SHOWN AT THE BERLIN INDUSTRIAL EXHIBITION IN 1879

ceeded in obtaining considerable speed and power, but his experiments were given up, as those of his predecessors had been, on account of the excessive cost of batteries as a source of electrical energy.

Three years previous, in 1847, however, Professor Moses G. Farmer had operated a small experimental model of an electric car, at Dover, N. H., U. S. A., and later, during 1850-51, aided by Mr. Thomas Hall, he exhibited at Boston, Mass., a model road on which a car ran back and forth, and automatically reversed its own direction of motion at each end of the road. This was subject to the same drawbacks as previous devices, due to the use of batteries. It is interesting, however, as one of the first known instances of the use of the rails, upon which the car ran, as a means of conveying the current from stationary batteries to the motor on the car. This model also embodied, perhaps more or less accidentally, the principle which is now almost universal, of running the motor at a high speed and gearing it down to a lower speed on the car axle, thus making possible the use of a smaller and cheaper motor for the power supplied.

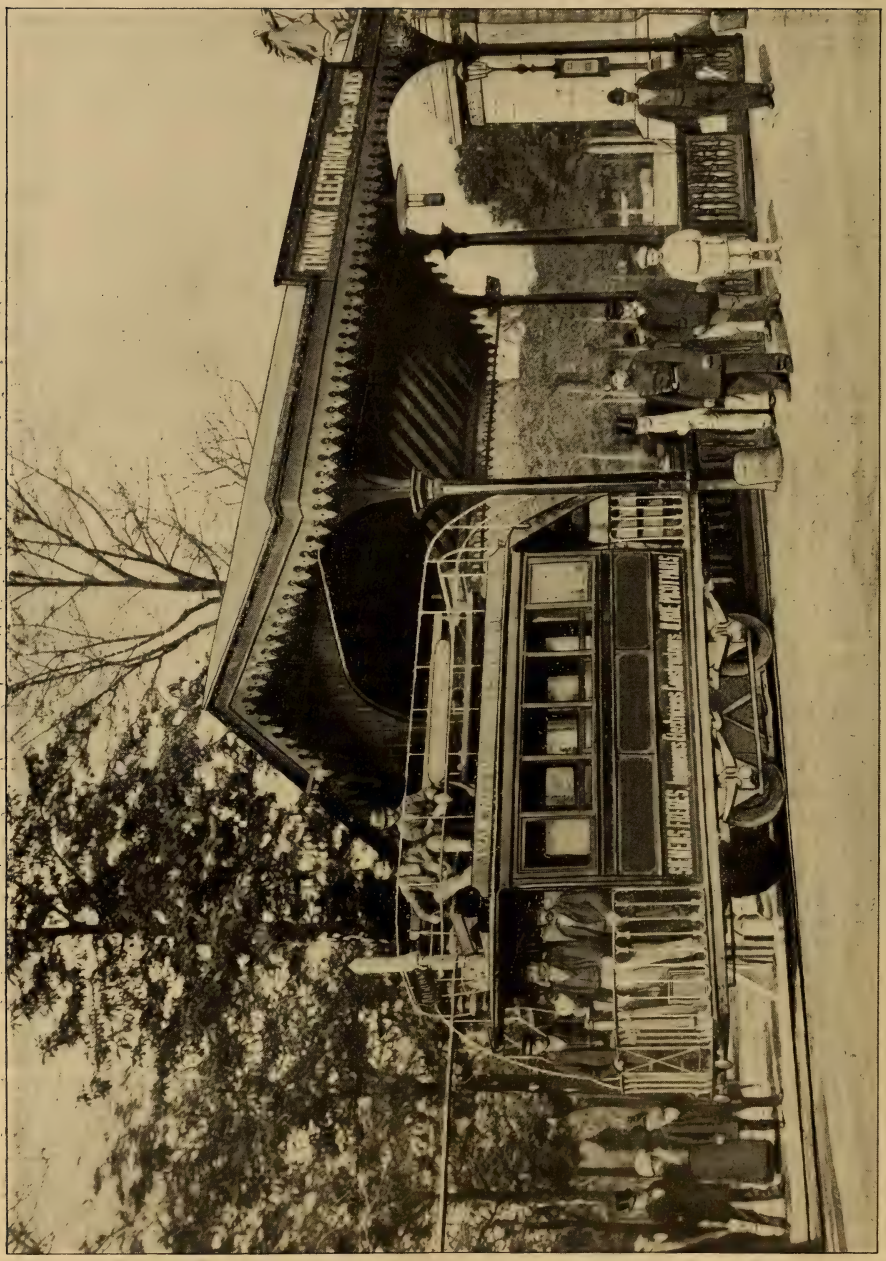
As has been just said, all these experiments were foredoomed to failure, because the enormously expensive primary battery had to be used as a source of power. It must be remembered that at that time the steam-engine was in its youth and the steam locomotive in its infancy. The law of the conservation of energy was known to but few, and fewer still understood or accepted it. The discovery of Ohm's law had been published but a few years, and a working knowledge of its use was mainly confined to mathematicians. The principles of motor design were not at all understood, while the dynamo had not been invented. It was a period, however, when inventors, scientists, and engineers were startling the world with new discoveries and wonderful achievements in the use of the energy of steam and other sources of power, and things that on one day had not been even thought of, were settled facts and almost commonplace on the next. It was natural, therefore, that these inventors should attack a problem the impossibility of solving which their lack of knowledge of the laws of electricity and of energy prevented them from foreseeing.

In 1864 the modern dynamo was born, but no one dreamed then, nor for many years afterwards, how large a part it was destined to play in the industrial progress of the world. Earlier inventors, discouraged by their lack of success, had turned their inventive powers into other fields, and did not realise that the one great obstacle to the commercial development of electric traction, the prohibitive expense of a battery as a source of power, had been removed with the advent of the far more economical dynamo.

It was not until eleven years later that any appreciable advance was made in the development of electric traction. Just as in 1835 a village blacksmith stood sponsor at the birth of electric traction, so in 1875, forty years later, a poor mechanic, George F. Green, living in the small American country town of Kalamazoo, in Michigan, rescued and revived the abandoned and almost forgotten idea.

Green's motor was a very primitive one, the armature consisting of an iron bobbin on which was wound a coil of fine wire, connected to a two-part commutator, which reversed the current in the armature twice during a revolution. He conveyed the current to his motor by means of an overhead line, using the track as a return. He used a battery as his source of power as he was too poor to buy a dynamo and did not know how to make one, although he perfectly well knew that his power must be derived from a dynamo if his invention was to become a commercial success.

About this time Mr. C. J. Van Depoele, who was afterwards one of the foremost inventors engaged in rendering electric traction practicable, was making experiments with motors; but it was not until 1883 that any public

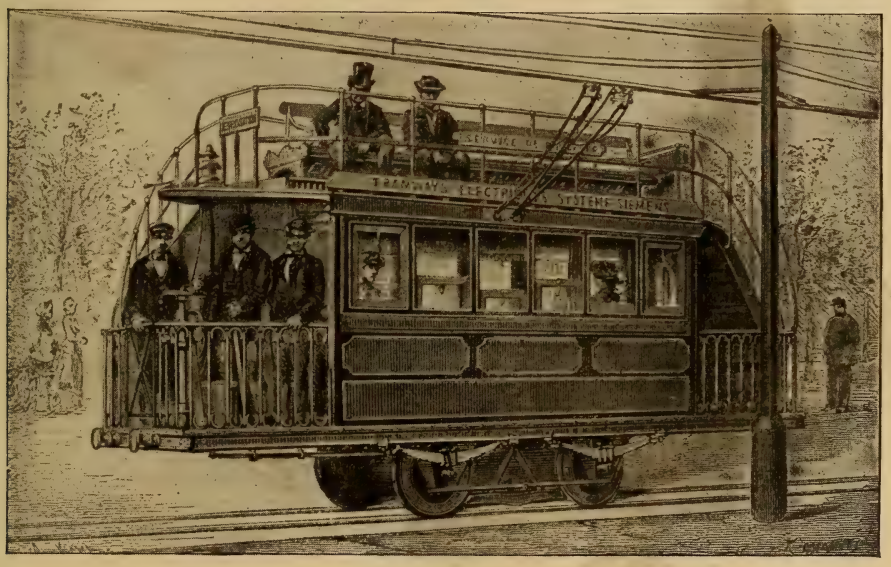


THE FIRST ELECTRIC RAILWAY WITH AN OVERHEAD WIRE AT THE PARIS EXPOSITION OF 1881

exhibition was made of his inventions in this direction.

In 1879 Mr. Stephen D. Field, in America, and Messrs. Siemens and Halske, in Europe, both were engaged on the problem. Field was handicapped by lack of money and by the fact that it was necessary for him to order a dynamo from Europe, as none suitable for his purpose was to be had in the United States. Siemens and Halske succeeded, however, in building what was probably the first electric railway on a practical scale. They used returned through the other; but this was a step backward, since this would have meant a shock to a horse or man who might happen to touch both rails at once. In 1880 Edison came into the field, but he does not appear to have made any radical improvements.

In Europe, Siemens was driving ahead with tremendous energy and enthusiasm, being engaged in the development of various schemes, including an elevated road with the working rails as conductors. He proposed running the speed up to forty miles an



A TROLLEY CAR IN PARIS IN 1881

what is now called the third-rail system for conveying the current to the motors, this rail being laid midway between the two upon which the car ran, and current being taken from it by means of a sliding shoe. Field was the first to suggest the use of a conduit for carrying the wires conveying the current, the method which is now so extensively used in New York City.

The success of Siemens's road in Berlin incited many inventors to work at the same problem. In the succeeding year Egger showed a model electric railway in which the current was conducted to the motors through one of the rails upon which the car ran, and hour, and for this purpose was the first to suggest placing the armature of the motor directly on the axle of the locomotive.

In May, 1881, the first commercial electric road, as distinguished from the previous experimental roads, was opened to the public at Lichterfeld, Germany. The next commercial electric road to be put in operation was opened to the public in 1883 at Portrush, in Ireland, using the third-rail method of supply. A noteworthy advance was made there in the use of turbines for driving the dynamos supplying the power.

From this time on progress was rapid,

and advances were made simultaneously by many different inventors. The idea of reinforcing the conductivity of the rails by auxiliary conductors was used in 1883.

Up to 1883 progress in the direction of commercially developing electric traction was mainly confined to Europe, but in that year American inventors assailed the problem with characteristic enthusiasm and recklessness. The Electric Railway Company of the United States, working under patents of Field and Edison, built an exhibition road for the Chicago Railway Exposition, which showed nothing new except auxiliary copper conductors to reinforce the conductivity of the rails. Van Depoele also constructed an exhibition road in that year, which showed no advance of any importance. Late in the same year Mr. Leo Daft constructed a locomotive to run on the Saratoga & Mt. McGregor Railroad.

During 1884 these men continued their efforts, and two new inventors put their shoulders to the wheel, which was slowly but surely gathering momentum. In July, 1884, Bentley and Knight, in Cleveland, Ohio, threw open to the public a slotted conduit road, the conduit being made of wood and placed between the rails. Their motor was hung from the car body midway between the two car axles, and was connected to the axles by means of wire cables.

A little later, in Kansas City, Mr. J. C. Henry erected the first practical overhead line in the United States. He had two trolley wires, on which ran a small carriage which made contact with the wires, and was drawn along by the car by means of a flexible copper cable.

In 1885 Mr. Daft continued his experiments, installing in Baltimore a road operated on the third-rail system. During the same year Van Depoele equipped an overhead line at Toronto, Canada, the trolley making contact on the under side of the trolley wire, as is done at the present time. For the next three years these inventors worked away in a more or less experimental way, gradually learning by disheartening failures, and by occasional successes, what methods must be abandoned and in what direction other devices must be developed and perfected.

Meanwhile, a new inventor, Ensign Frank J. Sprague, of the United States Navy, had come into the field. While in London, acting as a member of the jury at the Crystal Palace Exhibition at Sydenham, in 1882, he frequently rode on the Metropolitan District Underground Railway, and became impressed with the practicability of running electric trains between two planes, one being the track rails, and the other a rigid overhead rail following the centre line of all tracks and switches, connections to it to be by a trolley supported on a vertical arm having a universal movement and carried on top of the car over the centre of the trucks. However, he made no application for a patent on this until nearly three years afterwards, although in 1882 he elaborated the system of main and working conductors, the latter being carried between the tracks.

In the fall of 1885 he built for experimental work on the Thirty-fourth Street branch of the New York elevated railways the first single-gear motors, centered on the axle and flexibly suspended from the truck frame. These were the originals of the modern type of electric railway motor.

The years 1887 and, more particularly, 1888, mark an important era in the development of electric railways. In the early part of 1887 Sprague took contracts in Richmond, Va., St. Joseph, Mo., and Wilmington, Del., to run cars with overhead trolleys, with nothing to show but a blue-print of a motor, the experiments on the elevated railroad at New York, considerable experience gained in the development of stationary electric motors, and belief in possibilities for the future. Curiously enough, one of the first motors used in the Durant sugar refinery in New York, where Sprague conducted his early experiments, afterwards found active service in another sugar refinery in South Boston, and in September, of 1887, in

Philadelphia and New York, and in October in Boston, he operated experimental cars with storage batteries, and about the same time started an experimental car in St. Joseph. It was, however, in the year 1888 that the commercial advance was made. In that year several roads in the United States began to operate their roads and carry passengers under the practical conditions of a commercial street railway. Among the more important of these were the Sprague road at Richmond, one at Allegheny City, put in by Bentley & Knight, who had been working for a long time on the problem, and a third installed by the Thomson-Houston Company at Washington, D. C.

Sprague's technical training and his experience with stationary motors was of great service, for by means of a diligent study of the work of others and a thorough grasp of the causes of failure and of the best means of remedying defects, together with indomitable pluck, energy, and perseverance in the face of innumerable difficulties and disheartening failures, he finally succeeded in running cars carrying passengers with a promising degree of regularity. His was the first installation of an electric road on a large scale, and the natural difficulties of the route selected would be considered as offering a hard problem even in the present state of the art. There were heavy grades and many curves, some of them of very short radius, and one of the worst curves also included a heavy grade. When the first cars were run over the road, he had to station some of his men on the rear platform with instructions to get out and push when the car struck this curve, — "playing mule," they called it.

The lesson of this occurrence and many others of a like nature was not fully learned until driven home by many bitter experiences. This was the fact that all of the earlier inventors used motors of too small power for the work they had to do. When this lesson was learnt, there came the difficulty of designing motors of sufficient capacity, and, at the same time, small enough to get into the space available for them under the floor of the car and between the car axles. In order to make the motors small enough to get into this space and to decrease their cost and weight, it was necessary to run them at a high speed, and gear down to a lower speed at the car axle.

Various devices were used to accomplish this, such as belts, cables, cranks and connecting rods, bevel gears and others, but spur gears were finally found to be the most serviceable. Sprague hoped to use a single reduction with a pinion on the armature shaft and a large gear on the axle, but was finally forced to give up this idea because none of the manufacturing companies were, at that date, able to design a motor to run at the speed required for single reduction which would be small enough to get into the space at his disposal. He was forced, therefore, to put in an intermediate gear, into which the armature shaft pinion meshed, and which, in turn, meshed into the axle gear.

Sprague first suggested making the car truck a separate structure from the car body and proportioning this structure to bear the heavy strains brought to bear upon it by the motor. He also centered the motor frame upon the car axle by means of a sleeve cast on the motor frame and lined with a brass bushing within which the car axle could turn. This eliminated a great difficulty by keeping the centres of the gears at a constant distance from each other. It also enabled him to suspend the free end of the motor frame on springs, since that end could then have a certain amount of play up and down about the car axle as a centre without causing the gears to get out of mesh. The destructive pounding of the motor on the truck and on the rails was thus obviated.

While this lessened the sledge-hammer blow of the car wheels on the rails, the rails in use with the old horse cars were not heavy enough to stand the pounding that still remained, and the result was that the cars were soon running over a series of ridges like the waves of the sea, caused by the sinking of the rails between the cross-ties, and

A CAR ON THE FIRST COMMERCIAL ELECTRIC RAILWAY, INSTALLED AT LICHTERFELD, GERMANY, IN 1881, BY MESSRS. SIEMENS & HALSKE, OF BERLIN

the rail joints were battered out of shape until the bumping recalled the corduroy roads of earlier days.

The motors themselves were a never-ending source of trouble, both because they were not of sufficient power and because they were not well enough protected from dust and water. There were many other minor defects as well. The heavy loads brought on motors of small power were continually resulting in burn-outs, and the necessity for running the motors below the floor of the car and very near the ground made every mud-puddle between the tracks a source of anxiety, since the commutator and the windings of the motor were not protected or incased so as to keep the water out.

Copper brushes were used on the commutator. These were necessarily set at an angle to the commutator surface, so that, if the car ran backwards for even a very short distance, the copper leaves forming the brush would be bent and crumpled up, and sparking would ensue, followed shortly by flashing over and a burnt-out motor. Even if no attempt were made to run backwards, it was impossible to prevent the slight rebound of the car on stopping when the brake was put on hard or when the car was stopped on an up grade. Every night a large number of "cripples" would come limping into the car barn, and every available man was put to work to patch them up so as to keep the road going somehow.

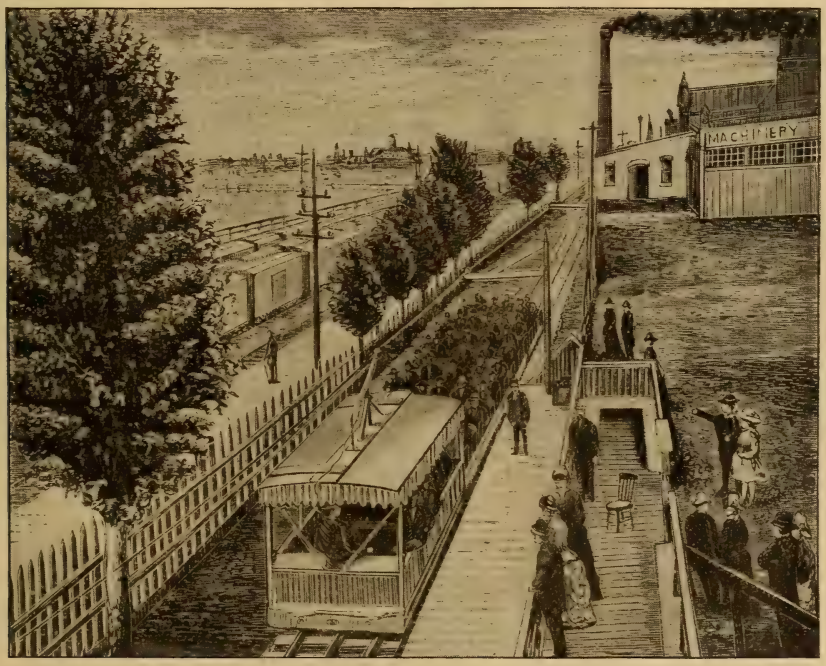
The power was conveyed to the motors by means of an overhead line with under-running trolley with the rails and the earth as a return. The trolley wheel was carried on a long pole, and was pressed up against the trolley wire by means of a spring on the car roof, the whole arrangement being substantially the same as the one used at the present day. Too much dependence was, however, placed on the earth as a return, and a large proportion of the energy was spent in overcoming the high resistance of the return circuit. The Bentley-Knight road at Allegheny City and the Thomson-Houston road at Washington were going through the same difficulties on a smaller scale, but

they all managed to scramble along, with the aid of unceasing vigilance and energy, and kept the cars running after a fashion.

It was evident, however, to those who were in the midst of the fray that the success of electric traction was now merely a matter of perseverance in overcoming minor defects; but it was necessary, in order to procure the sinews of war, that the public should be made to share their confidence, and many were the subterfuges employed to keep from the public a knowledge of the disheartening breakdowns and the immense amount of labour and ingenuity that had to be expended in order to keep the cars running.

Sprague finally decided to risk a demonstration of the success of the system, and invited a number of officials to a ride over the road at Richmond, with the customary body guard of faithful "mules" on the rear platform, Sprague himself handling the controller. All went well for a time, and the most difficult curves and grades on the road had been negotiated carefully and gingerly without any accidents. At last the car was on a straight and level street, and Sprague put on the full current with a light heart. Suddenly there came a splutter from underneath, and the "mules" on the rear platform felt the ominous chug and drag that told of a burnt-out motor.

Knowing that the machines were, as he expressed it, "red hot," Sprague, with a howling mob around who wished to see things "go," came back into the car, made some casual remark about circuits being wrong and the necessity of getting some instruments, turned out the lights and stretched himself out on a seat, while waiting for the crowd to disperse and the arrival of the "instruments,"—four powerful real mules to take the car back to the car barn.



THE FIRST ELECTRIC RAILWAY AT TORONTO, CANADA, 1885

Towards the end of the year these roads were gotten into such shape that the cars were kept going with a fair degree of regularity, and Henry M. Whitney, president of the large West End system of Boston, who was look-

THE WATER POWER OF THE PORTRUSH ELECTRIC RAILROAD, IRELAND, 1883

ing out for the best method of propulsion with which to replace horses, and who had almost decided on cable traction, was finally convinced of the advantages of electric traction over any other form, the Richmond road being the main factor in his conversion. As soon as it was known that this large company had decided in favour of electric traction, the public gained confidence, and electric roads began to spring up like mushrooms everywhere.

The electric railway had passed the inventive and experimental stage. The

entire practicability of electric traction on street railways had been demonstrated, and it was now the turn of the engineer and designer to eliminate defects and to perfect details. There were no more radical changes or innovations, but a steady growth.

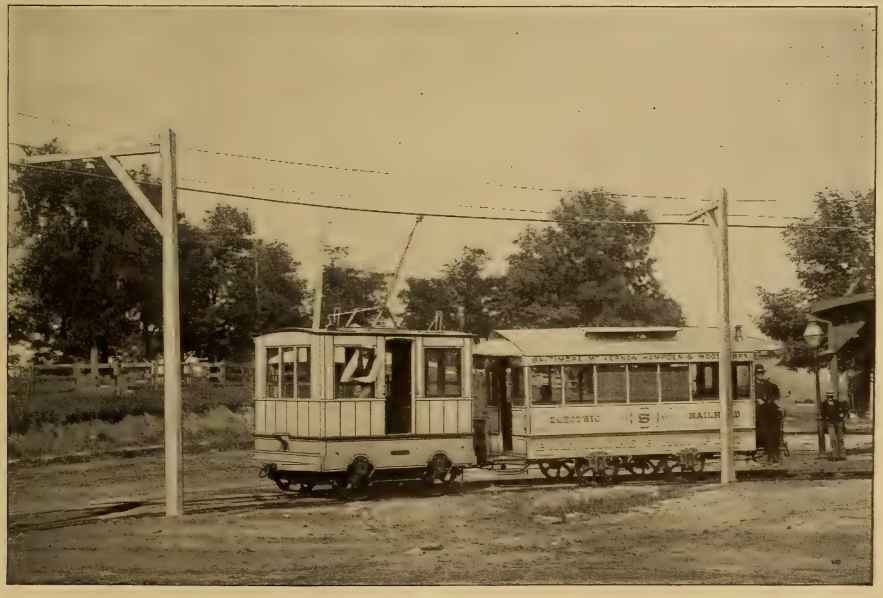
The motor problem was, perhaps, the most difficult one. The motors were increased in power and decreased in weight as designers gained experience. Carbon brushes, set radially to the commutator, were introduced by Van Depoele, so that the motor could be run backwards without injury to the brush or to the commutator. The field magnet was made up of such shape as to first partially, and finally completely, inclose the armature and the field coils, thus adequately protecting them from water, mud and dust.

By the utilisation of every available inch of space taken up by the motor, and by the use of better materials and better design, the motor was made more and more compact and its weight and cost decreased. Eventually, too, it became possible to make a motor to run at a slow enough speed for single reduction, thus dispensing with one gear.

As the motors increased in power, the truck had to be strengthened to stand the greater strains put upon it. The cars were gradually made heavier and larger, until they reached the limit of weight and length that a single truck was capable of carrying. Then came cars with two trucks, one at each end, the length of the car body being increased from 16 to 32 feet. The motors used in 1888 were rated at from 8 to 12 horse-power, while now they are rated at as high as 50 horse-power and more.

The constantly increasing weights of motors, trucks and car bodies necessitated a corresponding increase in the weight of the track and in the strength and solidity of the road bed. From *T* or flat rails, weighing from 25 to 60 pounds per yard in 1888, the rails have been changed to girders weighing from 70 to 100 pounds per yard, and the track construction of a modern electric street railway is as strong and solid as that of a steam road.

In 1888 the earth was largely de-



STREET CROSSING OF THIRD-RAIL ELECTRIC RAILWAY INSTALLED AT BALTIMORE IN 1885. THE OVERHEAD CONDUCTOR USED AT THE CROSSINGS CONSISTED OF GAS PIPE, AND CONTACT WAS MADE BY A BRUSH, MOUNTED ON A POLE, SIMILAR TO THE PRESENT TROLLEY POLE

pended on as a return circuit auxiliary to the rails, but this was very unsatisfactory, both on account of the difficulty of getting the resistance low and on account of the corrosion of gas and water pipes by the electrolytic action caused by the current. This forced engineers to the expedient of bonding the rails, or connecting them together at the joints by short pieces of copper wire. The two lines of rails were also connected to each other at intervals, so that if a bond became loosened at any one joint,—an accident very difficult to prevent,—the current would have an alternative path back to the power station. These bonds were sometimes also reinforced by an auxiliary wire, laid parallel to the track and connected to it at intervals.

The overhead conducting system, consisting of trolley wire and feeders, while presenting its difficulties, was probably the most easily solvable part of the problem. Some difficulties were met in properly insulating and supporting the trolley wire, but these were easily overcome compared with those in the other parts of the system.

The greatest danger was from lightning, and until three or four years ago on many roads during a severe thunder storm the cars would stop running and the trolley poles would be pulled down so as to escape the danger of having the motors burnt out by lightning. The designing of efficient lightning arresters was a difficult problem, but while the protection against lightning may not be absolute even now, yet there is no longer any special danger in running the cars through the most severe thunder storm, the power station, the line and the car being all efficiently protected.

Although, in the experimental stages of electric railroading, the current was, in some cases, conveyed to the motor by means of a trolley wire laid in a conduit under the roadbed, the overhead construction was so much cheaper and so much easier to insulate that the conduit, together with the third-rail system, was lost sight of in the tremendous rush to fill orders for the equipment of roads using the overhead system.

The manufacturing companies, fearing that the exploitaton of the more difficult and the more expensive conduit system would have a tendency to check the great demand for railway equipments, discouraged any attempts to develop it until the demand for equipments for roads using the overhead system commenced to slacken, owing to the fact that most of the street car lines had been already changed over to electric power. The companies then began to look around for new territory to conquer, and, seeing that there were several places where the overhead system was either not practicable or would not be tolerated, addressed themselves seriously to the task of developing a satisfactory conduit system.

The great difficulty was in insulating the trolley wire in a conduit under the roadbed, which was liable to be filled with water, mud or slush. This was finally obviated by making the conduit large enough to carry off the rain water or melted snow which might get into it, and by connecting it to sewers at frequent intervals. The trolley wire was supported near the top of the conduit, so that the latter had to be nearly filled before the water would reach the wire or get high enough to be thrown up against it by the trolley depending from the car. As the ordinary wooden sleepers could not be used to support the rails, cast iron yokes were made which held the conduits at their centres and the rails at their ends.

The best method of varying the speed and power of the motors also was a problem that taxed the ingenuity of the engineers. Mechanical means of doing this were suggested, but were quickly abandoned in favour of the electrical method. It was first effected by varying the resistance in series with the motor. Sprague used the commutated field method in his Richmond road, which consisted in changing the field coils from series to parallel and cutting out one of them altogether at times. This was done by means of a "controller" on the front platform operated by the motorman. For a time also an independent series-parallel switch was

used; but the current had to be cut off by the main switch before changing over, and it was abandoned, partly because of slipping of wheels on heavy grades.

The problem of very effectually reducing and destroying the arc was successfully solved by Mr. Potter and others of the Thomson-Houston Company, who used Professor Thomson's method, in which he took advantage of the peculiar property which a magnet has of repelling the electric arc. He placed at the point where the circuit was broken the pole of an electro-magnet, which repelled the arc formed at that point, and thus, as it were, blew it out.

The best general results were obtained when the "closed circuit series-parallel" controller in combination with the magnetic blow-out was designed. By means of this the two motors on a street car could be placed in series on starting and at slow speeds and changed to parallel at high speeds, thus largely reducing the loss of energy at low speeds.

The development of the central station and of the dynamos which generated the power for supplying the motors kept pace with the improvements in the other parts of the system. In 1888 the capacity of the dynamos employed was not greater than 40 kilowatts (about 50 horse-power), and they were belted to counter-shafts or to the fly-wheels of high-speed engines. As the principles of design became better known, the dynamos gradually grew in size, and the direct-connected dynamo was produced, in which the armature was mounted directly on an extension of the engine shaft. On account of the economy of space and the absence of complication that this change effected it grew rapidly in favour.

The high cost of direct-connected dynamos, due to their low speed, constituted a strong inducement to the designer to increase their size. In 1893 a 1500-kilowatt (2000 horse-power) direct-connected dynamo was exhibited at the World's Fair at Chicago, which was designed by Mr. H. F. Parshall for the General Electric Company, of New York. This was a notable achievement, since the largest direct-connected dynamo that had been previously designed was of but one third its capacity. On account of the large size of its members, it was assembled for the first time in the power house at the Fair grounds. It took up its load and ran without a hitch, and is still in use.

A 750-kilowatt (1000 horse-power) machine was designed at the same time, installed in the same station, and ran just as successfully. This size was not exceeded until within the last year, when a 1600-kilowatt machine was installed, and a 2500-kilowatt (3300 horse-power) machine is now being built in the General Electric Company's shops at Schenectady, N. Y.

The great and sudden variations in the power required from a railway generator necessitated a strong and heavy construction of the moving parts of both the generator and the engine. The output of the dynamo might in a second's time go from a 50 per cent. overload down to nothing. Such variations prohibited any movement of the brushes to suit the various loads, and it was necessary to design the dynamo so that when once the brushes were set in their proper position it would not be necessary to move them to prevent sparking at any load up to the full capacity of the machine.

In the early days of electric railroading the dynamos were protected from injury from excessive currents by means of lead fuses, which would melt and thus open the circuit when the current exceeded a certain limit. These are now almost universally replaced by magnetic cut-outs, in which a magnet is made to open a switch when the current becomes too heavy. This device has the advantage of being easily adjusted to cut out at any required strength of current and of quickly closing the switch after a short-circuit or excessive overload has come upon the system.

The latest development in railway central station practice, introduced within the last two or three years, con-

sists in what is called the multiphase system of transmission by means of alternating currents. In this system there is installed in the station an alternating current generator with step-up transformers which deliver current to the transmission lines at very high voltage. These lines are led to sub-stations at convenient points along the road where the high voltage is transformed down, and by means of rotary transformers, the alternating current is changed to a direct current, which is supplied directly to the feeders and trolley line. This high voltage on the transmission line makes it possible to place the power station at a distance from the railway, where land is low in cost, and coal and water are easily and cheaply obtained. The sub-stations can be constructed to take up very little space, and by being placed at frequent intervals along the line, effect a considerable saving of copper in the direct-current feeding system. This system also makes possible the utilisation of water power which may be available at some distance from the railway.

The street railway system at Buffalo, N. Y., furnishes an example of this method on a large scale, power from Niagara Falls being transmitted 28 miles, at 11,000 volts pressure, to Buffalo, where the voltage is transformed down, and the alternating current is fed to rotary transformers which deliver direct-current to the railway lines at 500 volts pressure.

One other system which should be mentioned here is that of self-contained accumulator or secondary battery cars. Despite the great advantage which would result from the source of power being carried upon the car, thus making each car a separate unit, independent of the rest, engineers have not yet been able to sufficiently overcome the difficulties due to the great weight of the batteries, the fragile nature of the materials employed in their construction and the disadvantages of the handling of the liquids forming the electrolytes, to make this system practically and commercially successful as compared with the other systems now employed. A few roads are now being operated on this system, but it is doubtful whether any of them will compare in cost, convenience or reliability with the overhead or conduit systems.

A difficulty which was triumphantly met by the electric railroads and which the horse-car lines had also to contend with, has not yet been mentioned, that is, the blocking of the lines by snow. The ease with which great power could be obtained on the electric systems was strongly in their favour, and snow ploughs and snow sweepers could, at a moment's notice, be put out on the road to clear it. The rapidity with which these machines could be made ready for work enabled the railway companies to clear the line of snow as rapidly as it fell or drifted on the tracks, so that there could be no great accumulation before removal.

The development of the high-voltage alternating-current distribution system previously mentioned has given a great impetus to the building of long suburban and interurban electric railway lines, and has made possible the utilisation of water powers at distances ranging as high as 50 miles. As methods of insulation are improved, so that higher voltages may be used, the limit of distance to which electric power may be economically transmitted will, no doubt, be greatly raised. This will result, in the near future, in the building of long lines between cities not too far apart and through thickly settled agricultural or suburban districts.

As to the adoption of electric traction on the trunk lines of large steam railway systems, it is doubtful whether this will come to pass for many years, largely because of the great expense of transmitting the power over the distances involved; but steam railways are, at present, very much alive to the possibilities of electric traction as a means of furnishing feeders to their trunk lines, and there will be a large development in this direction for a long time to come.

ELECTROLYSIS FROM RAILWAY CURRENTS

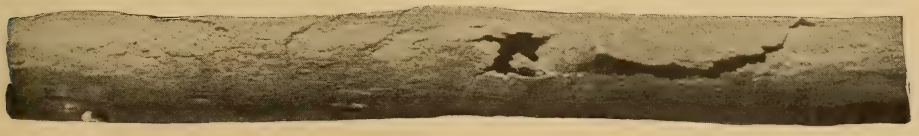
By Arthur Vaughan Abbott, C. E.

SEVERAL years ago much excitement and apprehension were aroused by the announcement that the underground metallic structures in many cities were menaced with destruction from the corrosive action of electric street railway currents. The extensive pipe plants of gas and water works were, it was averred, doomed to immediate disintegration, with the inevitable result that the inhabitants would be drowned, if they were not previously blown up. The lead sheaths of electric cables that, after a stubborn fight, had been torn from unsightly pole lines and thrust into subterranean conduits, were discovered to be not only in particular danger, but, when perforated, would furnish the igniting spark that would precipitate the general holocaust. The illustrated scientific press teemed with pictures of pipes in the most advanced stages of decomposition, and the opponents of the "deadly trolley" were filled with satisfaction at the efficiency of the new *casus belli*. Indeed, it seemed as if, in spite of its generally acknowledged convenience and utility, "the broomstick train" was doomed, and must, with the witch who hauled it, be relegated to the past.

But the inevitable reaction ensued. All the pipe systems did not immediately go to pieces, but, on the contrary, evidence from one town where the gas mains had been severely exposed, showed little injury, so that the railway people took heart of grace, and, emerging from the odium with which the "anti-trolleyites" had covered them, serenely proceeded on their way.

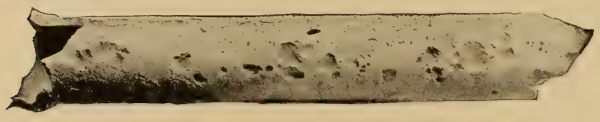
At present comparatively little is heard of electrolysis, but still electric currents from hundreds of power stations steadily creep through the earth, and while they may not inflict the predicted wholesale destruction, they are far from being harmless. Unless carefully controlled, they may, indeed, inflict considerable injury.

When electricity passes from place to place, a portion is absorbed in the bodies which form its path. In solids this dissipated energy is transformed into heat and expended, sometimes disastrously, in raising the temperature of the conductor, while in most liquids it is chiefly occupied in decomposing the fluid into its component chemical elements. Thus, if water form a portion of the circuit, it will be separated into oxygen and hydrogen, the oxygen appearing at the positive pole, or anode, and the hydrogen at the negative pole, or cathode. The elemental gases only make their appearance at the surfaces of the conductors extending into the



ONE YEAR'S CORROSIVE WORK ON AN IRON WATER PIPE

liquid, and, at the instant of decomposition, seem to be endowed with extraordinary activity, readily corroding all but the most resisting substances. This process of decomposing a fluid conductor, or electrolyte, is termed electrolysis, and, used in the art of electroplating, ante dating a few months the introduction of the telegraph, is claimed to be the first practical application of electricity.



ANOTHER SPECIMEN OF CORRODED WATER PIPE

Like fire, electricity is a good servant, but a bad master, and so long as it was usefully employed in coating spoons and forks, electrolysis proved itself a most valuable discovery. With the advent of the electric railway, however, a loophole of escape appeared, and the lightning that had been harnessed to deposit metals, carry messages, and drag cars, relieved from a confining path, wandered into the ground with mischievous intent, for in every trolley road electrical engineers had set up a gigantic electrolytic cell. With its engines and dynamos, the power station furnishes an almost inexhaustible supply of current that, passing through the trolley wire and car motor to the rails as one pole, finds in the moist earth a conducting fluid, and an opposite pole in the sundry metallic structures it may encounter on its return.

In an electrolytic cell corrosive action is confined to the anode. If the arrangement of railways is such as to make the rails the positive pole, disintegration would be confined to this portion of the circuit and cause dissatisfaction only to the railway owners. Such would be the case provided all subterranean metallic structures presented a path of less resistance than any other route. They would then be universally electro-negative, and no damage could result; but this is not the condition found in practice. A pipe line may parallel a track and then branch off. The joints between pipe lengths may be of comparatively high resistance, and at all such places electricity will seek the earth, with ensuing corrosion. So, while there cannot be the slightest ground for opposition on the score of possible injury to putting an indefinite amount of electricity *into* the underground systems, there is the most serious objection to its getting *out* again, excepting in so orderly a manner as never to make spots which are electro-positive, and the real problem is,—How shall all underground metallic plants be always maintained electro-negative?

Expedients galore have been proposed as solutions. To provide a complete metallic circuit, and, by thus preventing any current from entering the ground, secure complete immunity, is at first the most obvious and most radical proposition, but one which necessarily inflicts considerable hardship on railway interests. Immense sums are invested in existing single-trolley roads using the ground as a return circuit. To remodel these, to operate by some form of insulated circuit, would require an enormous outlay, regardless of mechanical difficulties. Certainly from the railway manager's point of view,

ELECTROLYSIS EFFECTS ON TELEPHONE CABLE COVERING

the double-trolley is impracticable, evidence of which is the survival of the single-trolley which has displaced the older metallic system, with which all early roads were equipped, and it is urged that, as electrolytic action can be confined to relatively small areas, it is unjust to require the reconstruction of entire railway systems, until it is shown that the danger spots cannot be suitably protected.

THE DOUBLE-TROLLEY, AN EARLY MEANS OF AVOIDING ELECTROLYTIC CORROSION

The alternating current has been held to provide a perfect relief and to obviate the constructive difficulties of the double-trolley; but this proposition, in avoiding a mechanical Scylla, steers into an electrical Charybdis, for there are practically no alternating current motors suitable for street railway work, nor, from the present outlook, is the advent of such apparatus likely. It seems hardly safe to assert that corrosive action would, by such substitution, be always entirely averted. Ordinarily chemical decomposition does not appear to attend the passage of alternating currents through liquid conductors, but the numerous devices for producing uni-directional currents from alternating circuits by the use of electrolytic cells, arouses a doubt as to the thoroughness of the promised relief.

Railways on the three-wire system, with the earth as the neutral conductor, furnish a solution particularly attractive to the railway manager, for under cover of an endeavour to prevent corrosion, the voltage may be doubled, and, theoretically, the cost of the feeder system reduced to one-fourth, while the earth is relieved of any currents but those which might pass laterally between the rails. But the three-wire system can be applied only to double-track roads, and excessive earth currents can be avoided only when both tracks are close to each other, and when the demands of the cars upon opposite portions exactly balance,—conditions that in practice can never, even approximately, be continuously realised. The hazard of two naked wires, differing by 1000 volts in potential, is incurred, and the currents in the earth as a neutral conductor constantly shift over the whole rail system, following changes in car load,

rendering the location of danger areas difficult, if not impossible. Yet in favourably arranged roads, and with intelligent design, this plan may prove valuable.

To obviate the mechanical difficulties of the double-trolley, it has been proposed to erect a complete feeder system of both outgoing and return conductors, properly insulated, and to connect the track at frequent intervals with the return wires, in such a manner that all paths to the station should be of equal resistance. The dynamos would be joined to proper feeder conductors, and no grounds allowed. Then the rails would carry current merely between any adjacent connections to the feeder system, and by making these sufficiently frequent, and by paying attention to good rail-bonding and adequate insulation, earth leakage may be completely avoided. While this plan is efficacious in preventing electrolysis, the cost of the conductor system is quadrupled for the same fall of potential, and there is a constant additional expense for the energy dissipated in the compensating resistance. This it is possible to reduce to any desired medium, but only by again increasing the expenditure for the conductors, which on any but very short roads would soon become prohibitive.

Such have been the principal plans for preventing electrolysis by keeping railway currents away from subterranean metallic structures; but as no harm can accrue from the entrance or passage of electricity, and as corrosion occurs only when the current leaves the metal for the earth, it seems pertinent to concentrate attention upon such points with a view to providing, if possible, efficient local protection. The first step is such a study of the territory as will enable its electrical condition to be ascertained. This information is best gained by an electrical survey. Where the area to be examined is small and the railway and underground systems simple, the early method of making voltmeter measurements between the water hydrants, lamp-posts and the rails and adjacent ground usually indicates with sufficient accuracy the points in the pipe systems which are positive to earth; but where the territory is extensive, and railway and underground systems are complicated, more comprehensive measurements are advantageous, and a thorough knowledge is best secured by drawing upon a map of the city in question a series of equipotential lines giving electrical contours. By selecting some desirable central point as a datum and taking advantage of the network of conductors that cover all towns, as electric light and power circuits, telegraph, telephone and fire alarm lines, the difference of potential between the datum and a sufficient number of points may

EFFECT OF ELECTROLYSIS ON AN IRON WATER PIPE ON 30 DAYS' EXPOSURE

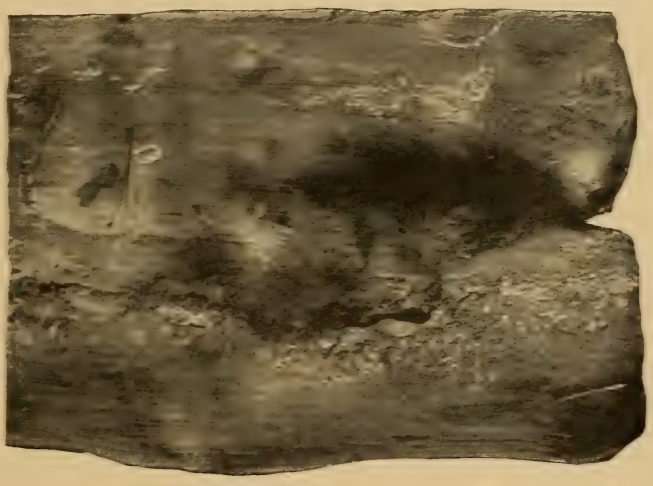
CORRODED LEAD PIPE

be rapidly measured. With the positive poles of station dynamos connected to the trolley wire, each station becomes the centre of a negative area that gradually diminishes in intensity. If the ground were of uniform conductivity, and if the tracks radiated equally in all directions, the equipotential curves would be a series of concentric circles with each station for a centre; but chiefly owing to eccentricities in the track system, the curves are expanded into irregular ellipses, the longer axes of which are essentially parallel to the rails. Proceeding from each station the potential gradually decreases to zero, and then increases to a positive maximum, so that the electrical condition may be compared to a rolling country in which each station occupies a deep hollow and is surrounded by a series of circular hills.

It is also desirable, with a view to estimating the probable amount of electrolysis, to determine the changes in earth potential that are likely to occur from time to time. This information is easily secured by a series of consecutive observations between convenient points which may be plotted as a curve showing the time-potential relation. Given an equipotential map, it is easy to determine the condition of the earth in any direction, and so ascertain probable danger points. If an imaginary plane be passed through the earth, its intersection with the equipotential curves will give a series of points forming a curve that represents the electrical condition along the plane.

Metallic structures that run parallel to equipotential curves lie in regions of constant potential and are unaffected; but if they intersect different equipotential lines, they will pass through territory of differing potential and the number of curves intersected in a given distance, or the steepness of the electrical gradient, is a measure of the probable tendency for the current to enter or leave the pipe line. Wherever the earth potential is falling or becoming more and more negative, the metallic structures will tend to be more and more electro-positive, for the current will endeavour to flow toward regions of least potential, and, conversely, in areas of rising potential, the pipe lines will tend to be electro-negative.

When railway electrolysis was first discovered, sweeping assertions were made as to the omnivorousness of the current in attacking, without respect, all metallic street structures, and laboratory experiments were cited to show that most minute differences of potential were sufficient to excite action. Practical experience has not fully sustained these early gloomy prophecies; contrariwise, it has been demonstrated that lead is the most sensitive metal, is attacked by the smallest difference of potential, and yields most readily and rapidly to corrosion. Wrought iron comes next, while cast iron, particularly those varieties that contain large amounts of carbon and silicon, known as white cast iron, are so little affected as to be almost exempt. The lead



SECTION OF A TELEPHONE CABLE COVERING FROM A CONDUIT

service pipes, therefore, from the water mains, and the sheaths of underground electric cables will be the first and chief sufferers. The wrought iron gas and water services, and the wrought iron pipes of the newer gas companies stand next, while the cast iron mains of the older installations, particularly those pipes made of chill iron, will practically escape injury.

The degree and rapidity of the corrosive action depends upon the quantity of current flowing, and the nature of the soluble salts contained in the surrounding soil. Chlorides or nitrates from the street wash in a clayey or loamy soil favour action, while in clean, dry sand, corrosion is a minimum. If corrosion were uniformly distributed over the entire surface of an exposed pipe, a measurement of the current and an analysis of the soil would enable a fairly accurate prediction as to the probable rate of injury, but as disintegration always proceeds by pitting, the damage is concentrated on particular spots, and the metal is perforated with comparative rapidity. As lead is most rapidly attacked, it is easy to test the probable maximum rate of action at any place by putting weighed test pieces of sheet lead in the street manholes and re-weighing them after a lapse of time.

The greatest economy in a local protecting system is attained by making it as small as possible, and the system is a minimum under the following three conditions:—

1. The danger areas must be reduced to their least dimension.

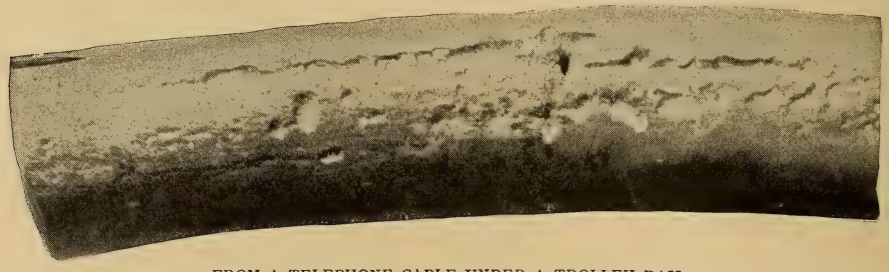
2. They must be brought as close as possible to the power station.

3. The current escaping from electro-positive points must be reduced to a minimum.

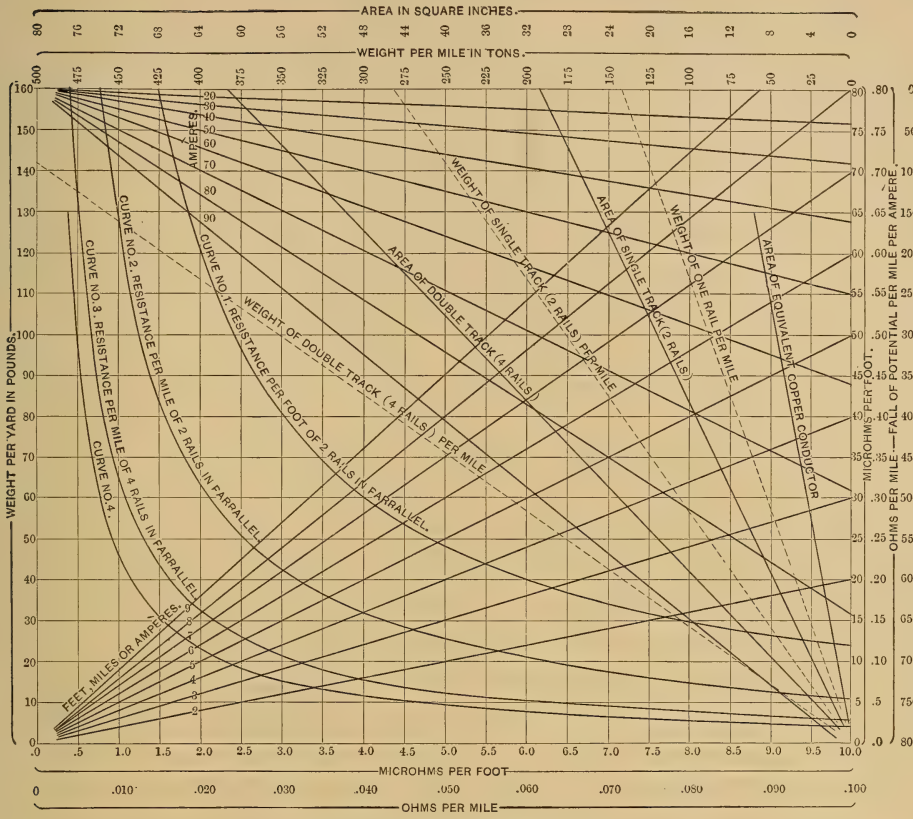
It was formerly the practice to connect the positive pole of the station dynamo to earth, and the negative pole to trolley wire, as shown in the upper diagram on page 378 with the result that the portion of the underground systems remote from the power house, covering a widespread territory, were rendered electro-positive, and the danger areas extended to the maximum limits, so the first step towards protection was taken by reversing the generator poles, rendering all the territory remote from the generators electro-negative and concentrating the electro-positive points in the immediate vicinity of the station. By this simple expedient, illustrated in the lower diagram on page 378, the first two of the three conditions have been fulfilled with the most gratifying results.

Compared to a metallic conductor, the earth, even in a most favourable condition of moisture, offers a considerable resistance, and it is only with great reluctance that currents of magnitude will leave even a naked metal path for the ground. Now in the metal of the track the railways have a conductor of magnificent proportions, far exceeding in electrical conductivity any feeder system in use, requiring only adequate electrical continuity at the joints to form a path that will permit only a minute fraction of the current to leak through the earth, thus tending to fulfill the third condition.

From the specific gravity and conductivity of steel it is easy to calculate the resistance of rails in terms of the weight per linear yard, and in the dia-



FROM A TELEPHONE CABLE UNDER A TROLLEY RAIL


AREA IN SQUARE INCHES.
WEIGHT PER MILE IN TONS.
AMPERES.
WEIGHT OF SINGLE TRACK (2 RAILS) PER MILE
AREA OF DOUBLE TRACK (4 RAILS)
AREA OF SINGLE TRACK (2 RAILS)
WEIGHT OF ONE RAIL PER MILE
AREA OF EQUIVALENT COPPER CONDUCTOR
CURVE NO. 2. RESISTANCE PER MILE OF 2 RAILS IN PARRALLEL
CURVE NO. 1. RESISTANCE PER FOOT OF 2 RAILS IN PARRALLEL.
WEIGHT OF DOUBLE TRACK (4 RAILS) PER MILE
CURVE NO. 3. RESISTANCE PER MILE OF 4 RAILS IN PARRALLEL
CURVE NO. 4.
FEET, MILES, OR AMPERES.
WEIGHT PER YARD IN POUNDS.
MICROHMS PER FOOT.
OHMS PER MILE.—FALL OF POTENTIAL PER MILE PER AMPERE.
C^2 R LOSS. WATTS PER MILE PER AMPERE.
MICROHMS PER FOOT
OHMS PER MILE

A DIAGRAM OF RAIL RESISTANCES

gram given on this page an attempt has been made graphically to set forth all information pertaining to the use of the rails as a return path. Curve No. 1 gives the resistance per foot of two rails in parallel, while Nos. 2 and 3 are the resistances per mile of two and four rails in parallel (single and double track). The left-hand scale is devoted to rail weight in pounds per yard, while on the lower horizontal margin are two scales. The upper one applies to Curve No. 1 and reads in micro-ohms per foot, while the lower one is for Curves 2 and 3, and reads in ohms per mile.

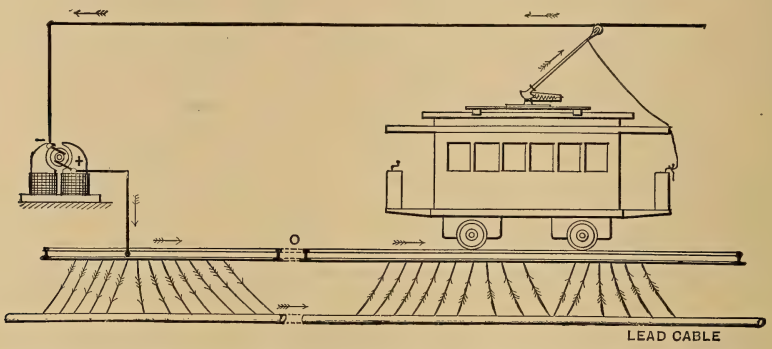
Thus, the resistance per foot of single track of 60-pound rail is found by selecting 60 on the left-hand scale and following a horizontal to Curve No. 1, then a vertical to the upper bottom scale, finding 4 micro-ohms. The resistance per mile of the same weight of double track is found in a similar manner, by using Curve 3, to be 0.0107 ohms.

By the diagonal lines radiating from the lower left-hand corner, and the two inner scales on the right-hand, the resistance of any number of feet or miles may be at once read. For eight miles of single track of 80-pound rail the resistance is found to be 0.125 ohms, by following a horizontal from 80 on the left-hand scale to Curve No. 2, thence a vertical to diagonal 8, thence a horizontal to the middle right-hand scale. As all scales are decimal, any range may be obtained by multiplying or dividing by ten, one hundred, etc.

Also, with the same diagonals and the second scale on the right-hand side, the fall of potential per mile may be calculated. To ascertain the drop per mile in a double track of 90-pound rails carrying 900 ampères, follow a horizontal from 90 on the left-hand to Curve No. 3, thence a vertical to the diagonal

9, thence a horizontal to the second scale on the right-hand, and multiply by 100, obtaining 6.3 volts.

From the upper left-hand corner a series of diagonals are drawn for calculating the energy expended in the track

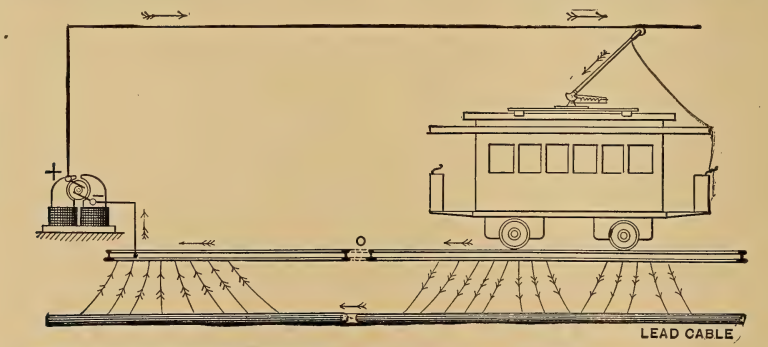


DANGER AREAS FROM ELECTROLYSIS EXTENDED TO MAXIMUM LIMITS BY THE OLD PLAN OF CONNECTING POSITIVE POLES OF STATION GENERATORS TO THE RAILS

portion of the circuit, and are to be used with the outer scale on the right hand. For example:—The power lost in a mile of single track of 70-pound rails carrying 30 ampères is found by following a horizontal from 70 on the left-hand to Curve No. 2, thence a vertical up to diagonal 30, thence a horizontal to the outer scale, giving 15 watts as the dissipated energy. As the

copper per yard of equal conducting power to any rail combination to be calculated. To obtain the amount of copper that must be supplied to be equivalent to a single track of 60-pound rails, follow a horizontal from 60 on the left-hand to Curve No. 2, thence a vertical to Curve No. 4, then a horizontal back to the left-hand scale, finding 21.8 pounds per yard as the required amount.

On the top of the sheet two scales will be found for use with the diagonals radiating from the lower right-hand corner. The lower one, "Weight per mile in tons," accompanies the three



GENERATOR POLES REVERSED IN ACCORDANCE WITH LATER PRACTICE, BRINGING DANGER AREAS NEAR THE POWER STATION

amount of energy consumed is in proportion to the square of the current, the outer scale must be multiplied or divided by 100, 10,000, etc., when the diagonals are multiplied or divided by 10, 100, etc.

Curve No. 4 enables the weight of

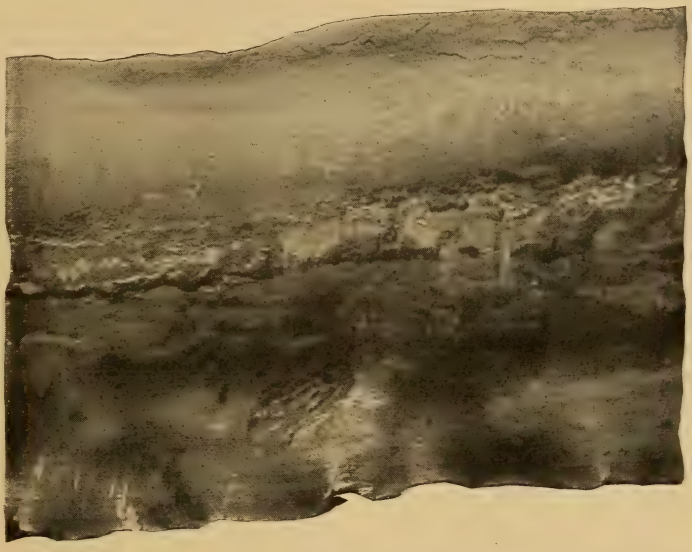
dotted diagonals, while the upper one, "Area in square inches," is used with the three full lines. With these scales the weight per mile or area in square inches of any rail combination, or area and weight per mile of a copper conductor having the same resistance, may

be found by following a horizontal from the weight per yard on the left-hand scale to the proper diagonal and then a vertical upward to the top of the sheet and reading the desired amount on the appropriate scale.

Only a slight study of the diagram is needed to discover the value of the track as a return circuit. A double-track road equipped with 80 pound rails would show a resistance of 0.008 ohms per mile. The fall of potential with a current of 500 ampères would be 3.9 volts per mile, while the energy dissipated would amount to 2000 watts, or less than one per cent. To supply a copper conductor of equal resistance, would require an area of 4.20 square inches, weighing 58 pounds per yard, or 25.3 tons per mile, costing about $8000, or £1600.

But in order to realise the full value of the rails, it is necessary to insure perfect electrical continuity,—that debatable ground upon which has been fought the battle of the bonds. While electrical discontinuity at the joints has always been recognised, its importance has always been underrated, owing to the exaggerated estimate of the value of the earth as a conductor. In early electric railway days the fish-plates merely were held to make a fair connection. Standard construction was a bit of No. 1 wire, riveted to a hole in each rail, with the addition, in gilt-edged work, of a No. 0 ground wire. Small wonder is it that electrolytic action caused the bonds to disappear so quickly as to make railway managers declare their maintenance an impossibility, or that the ground wires sometimes ran so hot as to actually burn the ties in two, and derail the cars by allowing the rails to spread. Could the record of the mountainous scrap heaps of burned out motors be correctly interpreted, the true epitaph of more than one defunct railway would be "Poor Bonding."

Recent experience has shown that in a street railway track properly supported by adequate paving, no allowance need be made for expansion, and that, except for convenience in handling, the rails might be endless. A continuous track would solve some of the most difficult problems, both electrical and mechanical, that confront the tramway engineer, and as a step toward such continuity, there seems to be little reason why track building of the future may not be done with 60-foot rails, thus reducing by one-half or two-thirds the present number of joints.



ANOTHER SECTION OF CORRODED TELEPHONE CABLE COVERING

For those that must remain, electrical welding from the conductivity standpoint presents the best solution, but mechanically the joint thus made is open to criticism.

The cast weld joint, from a mechanical point of view, seems at present the most perfect device for supporting rail ends,

but experience has demonstrated that there is not a perfect metallic contact between the rail and the casting, owing to the presence on the rail of an inevitable film of oxide, and the chill experienced by the molten metal when it first encounters the cold steel. A combination of the two methods would seem to attain the perfect joint, for the electrical weld, if properly made, would secure electric conductivity, while the casting would re-inforce a system otherwise mechanically weak.

All other methods of bonding are open to the difficulty of making and maintaining two electrically perfect contacts, at each joint between two dissimilar metals. In order that such a bond should be efficacious, it is requisite that the strip forming the conducting link shall have no greater resistance than an equal rail length, and that the area of contact shall not only be equal to the cross-section of the rail, but enough greater to provide a reasonable factor of safety against possible future impairment. In these particulars rail bonds in common use have utterly failed. The usual form of bond is a piece of No. 0000 wire, upset at the ends and riveted into the rail webs. Such a wire has an area of 0.166 square inch, and is equal in conductivity to only a 10-pound rail. An 80, 90 or 100-pound rail would require 1.25, 1.41 or 1.56 square inches of copper or eight, nine or ten No. 0000 wires. Between the rail web and a No. 0000 bond wire the surface contact is about 0.7 square inch, or a little less than the area of a 10-pound rail, while 80, 90 or 100-pound rails have areas of 7.68, 8.65 or 9.61 square inches, so that, without allowing any factor of safety, the bond should have ten and one-half, twelve, or thirteen times as much contact as is at present customary, for it is perfectly obvious that, if at any point in the return circuit the resistance is increased, a portion of the current will seek the earth.

Even by restricting the danger areas to a minimum, and with the aid of a perfect rail-return to reduce the earth currents to their lowest terms, the electrical survey will show some points where corrosive action is to be expected. As disintegration takes place only where current leaves the underground structures for the earth, the last link in the protective chain is forged by attacking the electro-positive spots directly, and preventing the passage of electricity into the earth. For this purpose it has been proposed to place an additional dynamo in the station, the negative pole of which is to be connected to the pipe lines by extra wires. If the special machine be operating a few volts higher in potential than the rest of the station, its action, to use rather an unscientific hydraulic analogy, is that of pumping the electricity out of the pipe lines, and so keeping them constantly electro-negative.

Doubtless this method is efficacious if a sufficient number of conductors are installed to reach from the special dynamo to all the electro-positive spots on the pipe lines; but if this additional set of wires be installed, the extra dynamo is superfluous, for the conductors may, at a very slight expense, be made of such low resistance compared with the soil, as to completely lead away from each electro-positive site all the current that would otherwise escape into the ground.

While a protective system may thus be easily made at a slight expense and completely fulfill the object for which it was designed, it is necessary to keep a close watch over its operation by means of repeated electrolytic surveys.

If the danger to which underground metallic structures are subjected from parasitic railway currents were irremediable, or if an efficacious protecting system could be secured only by incurring an expense out of proportion to the benefits secured, there might be a valid argument for the present state of the railway return; but when the protective system is easily and economically within reach, when its adoption largely contributes to the benefit of railway companies by reducing the expense for motive power, failure to adopt it is in the nature of a deliberate infringement of the rights of others, for which there can be neither legal nor moral excuse.

THE MUNICIPAL OWNERSHIP OF TRAMWAYS IN THE UNITED KINGDOM

By Benjamin Taylor, F. R. G. S.

AT a time when there is rather an exaggerated feeling in favour of municipalisation, it is of interest to consider what has actually been done in tramway undertakings by municipalities of the United Kingdom. It is not the purpose here to discuss the general question of municipal, as a form of State, enterprise, as against the individual or combined enterprise of citizens, but merely to set forth the facts regarding this particular form of municipal work.

As regards tramways, it is to be observed that municipal enterprise may take one of two forms. A municipality may construct and own the track, while leaving the working of the tramways to private individuals; or a municipality may both own the track and work the cars. There are several cases in which the track in the first instance was built by a company, and then purchased by the municipal corporation, which then either let the working to a company, or retained the business in its own hands.

Now as to the municipal ownership of the track, there is not much room for difference of opinion. It is, indeed, now generally admitted that in the case of a street railway it is desirable that the local authority, or municipality, should own the lines, so as to preserve complete control over the streets in the public interest. Where the track has not been, in the first instance, constructed by the municipality, difficult questions are raised when acquisition is desired. The interpretation of the purchase clauses of the Tramways Act of 1870 has provoked much legal controversy,—particularly in the case of London. The lesson which all municipalities may now deduce from the experience of London and other cities is, that when a tramway system is projected, it will be better and cheaper for the municipality to construct and retain the ownership of the track from the outset than to allow a company to construct with a view to ultimate purchase by the local authority. There is a general consensus of opinion, confirmed by experience, that municipal ownership of the tramway track is not only profitable, but, as a general rule, most desirable.

When we come to the question of operating, however, there is a wide difference of opinion. It seems to be a well-established fact that no municipality can conduct any enterprise as economically and efficiently (from a commercial point of view) as can individual traders working on ordinary business principles. On the other hand, a municipality does not aim at pecuniary profit,—at all events not in the first instance,—but at the greatest good for the greatest number of citizens. Thus it is not easy to find a common plane on which to compare municipal with private enterprise in such active work as tramway management. But, generally speaking, the writer is of the opinion that the most perfect tramway system is procurable when the municipality owns the track and leases the

lines to a company under municipal regulations.

It is not conceivable that any committee of a fluctuating body like a town council can have the same grasp of the business of tramway management as a permanent board of directors, each with a large pecuniary interest in the undertaking; or that the chairman or convener of a municipal tramway committee can have the knowledge, experience, and devotion to the work, that a general manager ought to have. Each such committee has to purchase,—and pretty dearly, —the experience with which a tramway manager starts. Hence the story of municipal enterprise is a story of blunders,—when it is not one of disaster. And even when there is a general manager, fully endowed with responsibility and powers, he is always more or less subject to the control of the committee, which may change in composition every year, and does change very frequently. Each committee has its own fancies and fads, or is controlled by a "strong" member whose views are not always those of the general manager. All this does not make for perfection of management.

Let us now look at some of the results of municipal enterprise in the United Kingdom! The following is a statement of the number of street and road tramways authorised by Parliament up to June, 1897, and shows how they were promoted:—

	Promoted by			
	Local Authorities.	Incorporated Companies.	Joint Stock Companies.	Private Individuals.
England & Wales	35	32	60	7
Scotland	6	4	4	--
Ireland	--	15	1	--
Total in United Kingdom	41	51	65	7

This gives a grand total of 164, of which, however, five were not opened for traffic at the date of the returns. The local authorities entered as owners of their respective tramway systems are the corporations of Accrington, Barrow-in-Furness, Birkenhead, Birmingham, Blackburn, Blackpool, Bolton, Bootle, Bradford, Croydon, Dover, Eccles, Keighley, Huddersfield, Hull, Liverpool, Leeds, London, Manchester, Moss-Side, Newcastle-on-Tyne, Newport (Mon.), Oldham, North Bierleys, Plymouth, Preston, St. Helena, Salford, Shipley, Sheffield, Southport, South Shields, Sunderland, Tong, Wigan, Withington, Edinburgh, Glasgow, Gourock, Govan, Dundee, and Greenock. None of the tramways in Ireland were either constructed by, or owned or managed by, local authorities. The total number, length and capitalisation of tramways in the United Kingdom is divided as follows between municipal and private (or company) enterprise, according to the Board of Trade figures for the tramway year ended June 30, 1897,—which are the latest figures available at the time of writing:—

Tramways belonging to	Number of Undertakings.	Capital expenditure on lines and works open for traffic.	Total capital expenditure.	Length Open for Traffic. Double miles.	Single miles.	Total miles.
Local Authorities	42	£3,222,438	£4,459,488	203	164½	367½
Other than Local Authorities	117	8,177,735	10,405,622	272½	391	663½
Total	159	£11,400,173	£14,865,110	475½	555½	1031

In the capital expenditure on tramways belonging to local authorities is included certain expenditure by lessees on buildings and equipment for working the lines; and in the capital expenditure on tramways belonging to other than local authorities is included the cost of equipment of some lines belonging to local authorities which are worked in conjunction with other lines. By a local authority is meant either a corporation, a district or county council, or a board of police, and in speaking of municipal interests all these local authorities are included.

The above figures are comprehensive enough to show the division of the tramways system of the United Kingdom to be rather more than one-fourth the

result of municipal, and rather less than three-fourths the result of private (or company), enterprise. But municipal ownership of the track is, as has been said, a very different thing from municipal working of the tramways. Of the forty-two undertakings grouped above as belonging to local authorities, only six are actually operated by the local authorities themselves in the municipal interest,—or, at all events, at the municipal risk,—viz., Glasgow, Leeds, Huddersfield, Blackpool, Plymouth, and Sheffield. In all other cases the tracks constructed, or acquired, by the corporations (or other local authorities) are let on lease for varying terms of years, and on varying conditions, to operating companies.

The Liverpool tramways were, until the end of last year, owned by the corporation and worked by a lessee company. This system is now, however, being worked as a municipal undertaking by a committee of the corporation, but as a municipal enterprise it affords no data for the present purpose. Heretofore the Liverpool tramways have been worked by horse haulage, and the corporation now propose to introduce electric traction by the overhead trolley. When mechanical haulage is thoroughly established, it is proposed to institute a uniform fare, within the limits of the municipality, of twopence inside and one penny outside, per journey. This would permit of a possible journey of six miles for one penny, and the wisdom of offering such an option has been much questioned. Sir Arthur Forwood, however, who is chairman of the committee, and who advocates the uniform-rate system, estimates that there will be a surplus of £8000 per annum after meeting all costs of working and providing for interest and sinking fund.

Such an estimate of the product of an untried system cannot be regarded as anything more than guess-work, based on a theory of probabilities. It goes, however, on the supposition that on 80 miles of single track 3400 round journeys per day shall be made by the cars, involving a total run of 26,000 miles per day. The cost of this installation is estimated at £1,100,000, the annual working expenses are placed at £174,000, and the sinking fund and interest at £6000 per annum. The increased traffic to produce the revenue is hoped for from the temptation of a penny fare inducing the working river-side population to find dwellings in other parts of the city and suburbs.

Excluding Liverpool, we have the experience in the United Kingdom of only six municipalities who operate, as well as own, the tramways. These are as under, with the respective populations, miles of track and gauge:—

Municipality.	Population.	Miles of Route.	Miles of Track.	Gauge.
Glasgow	840,000	35	67	4 ft. 7¾ in.
Huddersfield..	100,000	20	22	4 " 8½ "
Blackpool.....	35,000	3	4	4 " 8½ "
Leeds.....	400,000	18	30	4 " 8½ "
Sheffield.....	380,000	9	18	4 " 8½ "
Plymouth.....	90,000	4	5	3 " 6 "

The Dover tramways (3 miles) recently constructed are also operated by the corporation, but the line was opened only in September last, and no returns have been available.

Huddersfield was the first town in Great Britain to set an example in the municipalisation of tramways, and the enterprise there has been such a signal failure that it is a wonder any were found to follow suit. During every one of the fourteen years of municipal operation there has been a loss, sometimes as high as £16,000, sometimes as low as £600. The total loss has been estimated at £60,000, which has been met by an assessment on the rate payers. This tramway rate which began at a fraction of a penny per pound, has, in some years, been five-pence per pound, of the rateable rental.

It has been sometimes supposed that the non-success of Huddersfield is due to the use of steam traction,—an expensive form of haulage. This, however, is hardly reconcilable with the fact that in other towns steam traction is employed by companies with profit. The real explanation is that in Huddersfield the lines have been extended in response to the demands of cliques sufficiently well represented in the town council to gain attention, instead of in

compliance with the claims of traffic. We may put it that the public convenience has been consulted in these extensions, rather than prospective profit. This may be municipalisation, but it is not business, and Huddersfield affords a standing object-lesson of the dangers which attend this form of municipal enterprise. The following summarises last year's returns of Huddersfield tramways (20 miles) worked by the Corporation:—

Capital expenditure		£138,974
Gross receipts from passeng's	£28,856	
" parcels and mails	455	
" other sources	929	
		£30,240
Working expenditure:		
Maintenance of way & works	£1,330	
Locomotive Power	7,477	
Repairs & renewals of engines	4,001	
" " " cars	1,250	
Traffic expenses	2,953	
Management expenses	1,060	
Rents, rates & taxes	1,113	
Compensation	271	
Other charges	571	
		20,026
Net receipts		£10,214
Number of passengers carried		4,616,960
Number of car-miles run		427,466

The Leeds tramways have been operated by the municipality for three years. In the first year there was a surplus of net earnings equal to about 1 per cent. on the capital expenditure, as compared with a dividend of 7 per cent. which the lessee company had earned and paid in the previous year. In the second year there was a surplus barely equal to the requirements of the sinking fund. A municipal tramway cannot be accounted a financial success if it cannot do something more than meet its capital charges,—for all these municipal enterprises are conducted on borrowed money. The following is the summary for the year ended June 30, 1897:—

Leeds Tramways (18 miles) worked by the Corporation.

Capital expenditure		£210,699
Gross receipts:—		
From passengers	£62,491	
" parcels and mails	389	
" other sources	1,346	
		£64,226
Working expenditure:—		
Maintenance of way and works	£3,031	
Locomotive power	11,298	
Animal power	15,128	
Renewal of horses	2,173	
Repairs and renewing of cars	3,496	
Traffic expenses	10,562	
Management	450	
Rents, rates and taxes	1,982	
Compensation	423	
Other charges	2,019	
		50,562
Net receipts		£13,664
Number of passengers carried		14,203,397
Number of car-miles run		1,223,183

The Blackpool system is a small affair. As a municipal enterprise it has been in operation for four years and has just managed to pay its way. When out of net receipts a fair charge has been taken for depreciation and interest upon the invested capital, there have remained on the four years' working a few hundred pounds to the good. This poor result contrasts with the fact that when the Blackpool system (which is an electric conduit one) was worked by a company, it paid good dividends. The following was the result last year:—

Blackpool Tramways (5 miles) worked by Corporation.

Capital expenditure		£62,934
Gross receipts:—		
From passengers	£13,121	
" parcels and mails	47	
" other sources	321	
		13,489
Working expenditure:—		
Maintenance of way and works	£1,613	
Locomotive power	1,767	
Animal power	108	
Repairs and renewals of engines	2,042	
" " cars	592	
Traffic expenses	3,006	
Management	228	
Rents, rates and taxes	554	
Compensation	.....	
Other charges	412	
		10,322
Net receipts		£3,167
Number of passengers carried		1,938,332
Number of car-miles run		204,736

The case of Plymouth is one not of voluntary, but of compulsory, municipalisation. A company which had the tramways, abandoned the enterprise and forfeited its charter, and the corporation had to take over the whole undertaking. In the following return there is no allowance for depreciation and interest. Were these fully charged in the last financial year, a considerable loss would be shown instead of a nominal surplus:—

Plymouth Tramways (5 miles) worked by corporation.

Capital expenditure		£56,358
Gross receipts:—		
From passengers	£8,258	
" parcels and mails	55	
" other sources	396	
		8,709
Working expenditure:—		
Maintenance of way and works	68	
Locomotive power	.....	
Animal power	2,583	
Renewals of horses	449	
Renewals and repairs of cars	219	
Traffic expenses	2,950	
Management	323	
Rents, rates and taxes	323	
Compensation	6	
Other charges	290	
		7,211
Net receipts		£1,498
Number of passengers carried		1,981,920
Number of car-miles run		181,393

The corporation of Sheffield, in July, 1896, undertook the working of the tramways, the track of which already belonged to the municipality. It had been leased to a company which had paid dividends of from 5 to 8 per cent., —the largest division being in the last year of the lease. In the first half-year of corporation working, a surplus was shown of £5483, and in the second half-year one of £6111. But in figuring out these surpluses no allowance is made for depreciation, or interest, or for the mileage rental paid by the leasing company to the corporation, which amounted to some £4000 per annum. The following is the corporation statement for the past half-year ended December 31, 1897:—

SHEFFIELD TRAMWAYS.

Receipts:—		
From passengers	£27,006. 0.3	
" advertisements	320 12.3	
" stable refuse	65. 5.0	
" sale of horses and car-cases	202.15.6	
From old car	5. 0.0	
" summonses, etc.	1. 3.0	
" sale of refuse	12. 8.10	
		£27,613. 4.10
Additions to property out of revenue		832. 5. 6
		£28,445.10. 4
Expenditure:—		
On running account (forage, wages, etc)	£11,390. 3.7	
On traffic account (maintenance, repairs, etc.)	4,576.14.0	
On general charges	3,628, 1.5	
		19,594.19. 0
Surplus, being gross profit		£8,850.11. 4

Out of this surplus has to be paid interest on the capital expenditure (stated in the Board of Trade returns at £118.9.0), depreciation on horses and working-plant (to be superseded by an electric installation), and allowance to the common fund of the city in name of rental of the streets, such as the company paid. If these items be duly accounted, the surplus will probably be found wholly imaginary.

The following are further details of the Sheffield undertaking in the two last half-years:—

	Half-year Ended June 30, 1897.	Half-year Ended Dec. 31, 1897.
Mileage, double	9	9
Number of miles run	383,597	390,067
Number of passengers carried	4,471,136	4,947,050
Average number of daily cars	37.21	38.08
" pass. per car per week	4,647	4,942
" number of horses	360	370
Receipts from pass'ers.	£24,595. 0. 0	£27,006. 0. 0
" per mile run	15.38	16.23
" " " of tram.	2,732. 11. 6	3,000. 13. 4
Average receipts per car per week	25.11. 2	26.19. 7
Average cost of forage per horse per week	7. 9	8. 1½

As in Glasgow is to be found not only the largest, but also the only apparently successful, municipal undertaking in tramways, a more detailed study of that system is desirable. The tramway system of Glasgow was not initiated by the corporation, and it was not until, in 1870, two rival companies sought Parliamentary powers to lay down street tramways in the city, that the town council interposed and acquired the power to make the track itself, with the option of either operating or leasing the enterprise.

The British and Foreign Tramway Company, as the promoters of the system, became the first lessees. This company assigned the lease and concessions for £350,000 to the Glasgow Tramway and Omnibus Company, which thereupon took up all the obligations with the corporation, including the thorough initial equipment and maintenance of the line. The actual cost of the lease to the operating company was about £180,000,—a heavy fine to pay at the beginning of a new enterprise, and a formidable addition to the capital charges of the new company.

The lease of the Glasgow Tramway Company was for 23 years from July 1, 1871, and under it they had to maintain the track, constructed by the corporation, in good working order, to keep up the roadway for a certain distance on each side, and, at the end of the lease, to hand over the lines as good as new. To insure the fulfilment of these conditions they had to set apart every year a sum equal to 4 per cent. of the cost of construction of the line,—which cost ultimately amounted to £344,965. To the corporation the company had to pay a rent equal to £150 per mile of track actually in use, a sum of 3 per cent. per annum on the capital cost of the line to form a sinking-fund for the redemption of the debt, and all the expenses of the corporation in connection with the tramway system. Securities were lodged

by the company for the fulfilment of the contract and the corporation retained the right to make by-laws for the regulation of the traffic, and other details.

The first section was opened for traffic in 1872, and the company continued to operate with success until 1894, when, having declined to accept the conditions on which the corporation offered a renewal of the lease, their occupancy terminated. For the first two years the company paid no dividend, but in 1875 it paid 3⅛ per cent., and then went on steadily improving until from 8 to 10 per cent. per annum was divided among the shareholders, after the large payments to the corporation had been satisfied, and a sum set apart to wipe off the value of the lease by the time it should terminate.

In short, the Glasgow Tramway Company was a highly successful undertaking due to three main facts,—the rapid growth of the city and the absence of competition for internal and suburban traffic; excellent management; and, very largely, the extremely low prices of fodder during the last twelve years or so of the lease.

When, however, the time came for the company to quit and for the corporation to enter upon working possession, there was a very regrettable waste. So much friction had been generated between the two bodies during the abortive negotiations for the renewal of the lease that they could not come to terms for the transfer of plant, cars, stud and stabling. The corporation, at great cost, set to work to build new stabling and new cars, and to import some 3000 horses, while the company had to sell their old cars practically for matchwood, and to get rid of the horses as best they could. Thus the company ended with a heavy loss of capital which might have been avoided, and the corporation started with an unnecessarily large expenditure of capital on preliminary equipment. This is another example of municipal, as compared with ordinary business, methods.

The corporation began to operate the Glasgow tramways in July, 1894, with a completely new equipment, but still with horse-haulage. Halfpenny fares for half-mile stages were instituted, and although the old tramway company commenced an active competition with the cars by means of smart, well-horsed omnibuses, the tramway traffic began to expand at once and has gone on growing almost continuously ever since. To this expansion of traffic and the continued low price of fodder,—an item of enormous importance with a stud of upwards of 4000 horses,—Glasgow owes the circumstance that the Tramway Department has paid its way under municipal management.

Needless to say that management is much more costly than under the company. Wages were raised, hours of labour were reduced, ticket inspectors and other officials were increased, uniforms were provided, trace-boys were multiplied, and so forth. But the service of cars also was very greatly increased, new routes were opened up,—not to please individual residents, but on a well-conceived plan of traffic development,—and the halfpenny fare encouraged the constant use of the cars on all portions of the routes by all classes of the citizens. The institution of the halfpenny fare has been claimed as a proof of the wisdom of Glasgow municipal management; but the halfpenny fare was not invented in Glasgow, nor did it originate in a municipal undertaking. The Glasgow corporation simply took the hint from the London Tramway Company, and the city happens to be peculiarly well adapted to the system.

Naturally, the corporation of Glasgow had many difficulties to contend with in entering upon a new business of such an extensive character all at once. The company ceased operations at midnight of June 30, and the corporation had to begin work over the whole system at six o'clock the next morning, with fresh horses and new men. Yet at the end of the first year they showed a surplus of £24,204, which was somewhat fancifully called "profit," out of which had to be allotted depreciation and a payment to the Common Good (or municipal capital fund) in respect of

the charge on the capital invested in construction. This capital investment is valued, for the purpose of the department, at £143,000. The actual cost of the construction of the line up to the time of the termination of the lease was £344,965, but of that the sinking-fund of the company (with interest on accumulations) repaid £201,470, leaving a balance of debit of construction account of £143,495. At this valuation, therefore, the track was handed over to the tramway committee, which, in return, has to pay £9000 per annum to the Common Good. This is a first charge on the undertaking and is practically rent.

The tramway committee has also to recoup to the municipal treasury a further rental for right-of-way in the shape of a mileage rate (£3000 or so per annum), interest on the money advanced for the equipment of the line, a sinking-fund, and a renewal fund. If the revenue is insufficient to meet all these charges, the corporation of Glasgow cannot (although they tried hard to obtain the power to do so), like Huddersfield, make it up by taxation. They can make ends meet only by cutting down expenses,—which means wages,—and that would arouse a storm of resentment among an army of electors; by raising the fares again, which would, doubtless, have the effect of materially reducing the receipts, as there are now three underground railways competing; or by reducing the service of cars on overlapping routes.

They have, however, in reserve a potential source of revenue in the advertising public. The company used to make several thousands per annum by letting the insides and outsides of the cars to advertisers, and there is little doubt that the corporation could now make twice as much as the company did out of this. But it is not considered municipally dignified to do so,—another example of municipal, as contrasted with ordinary business, ideas.

The Glasgow tramway accounts are kept on a system which has provoked a good deal of criticism, and which certainly would not be permissible in an undertaking carried on for profit. For a municipal enterprise, carried on for the service of the public, and not for the profit of individual proprietors, the system may be reasonable enough. It does, however, serve to show a surplus which, in a commercial enterprise, would not be recognised as profit. In the last tramway year, ended May 31, 1897, the receipts were £370,882, and the working expenses, £286,286, leaving a balance of £84,596, as compared with one of £83,267 in the previous year. On the year the receipts had increased by £36,505, but the expenditures had also increased by £35,176, so that the addition to income was nearly all absorbed in expenses. This is a point worth noting, because in this financial year the cost of fodder was the lowest on record, viz., 6s. 11½d. per horse per week, and a good deal lower than it will average in the present year.

One cause of the increased expenses was an addition to the wage-bill, equal to £5300 per annum, under what must be regarded as municipal pressure. The following are some of the principal points in the Glasgow working:—

	1897	1898
Number of miles run	8,127,111	6,932,650
Number of passengers carried	98,966,658	86,462,594
Average number of cars	268	227
Receipts per car-mile	10.95d.	11.57d.
Working expenses car-mile	8.45d.	8.69d.
Maintenance & renewal of permanent way	£33,877	£16,332

Repairs and renewals of horses, rolling-stock, buildings, and equipment, were all paid out of revenue, and the surplus was £84,596, as above stated. Out of this surplus £36,086 went for rent (to Common Good and to the corporation of Govan), interest on capital, and sinking-fund, which last, at 2 per cent., is calculated to wipe off the debt in 33 years. Other items written off were, £13,510 for depreciation, £15,000 for a permanent way renewal fund, and £20,000 for a reserve fund, which book entries dispose of the balance. As nothing is paid away in the shape of dividends, it does not, perhaps, matter much how the balance of revenue over working expenses is disposed of in the corporation books. At the same

time, it is obvious that an item of £13,510 is quite inadequate for depreciation of horses, cars and plant, in view of the intention to replace horse haulage at an early date with mechanical motors.

The price of the horses has been written down to £26 per head, which price could not be obtained if the whole 4500 or so have to be sold as the old company had to sell theirs. As the horse-cars are not suitable for either electric or cable haulage, they will be practically valueless when the change to the new system takes place. Not to write down these items heavily year by year out of ostensible profits, is to ensure future large additions to the capital account. And the ostensible profit on the Glasgow tramways is liable to be swept away any year while horse haulage is maintained, by a rise in the price of fodder or by an epidemic among the stud. As the fall in fodder in 1897 was equal to a saving of £5000 on the expenditure of 1896, it is evident that the municipality of Glasgow is engaged in a much more risky business than it has yet realised. There is trouble ahead if mechanical haulage be not soon adopted.

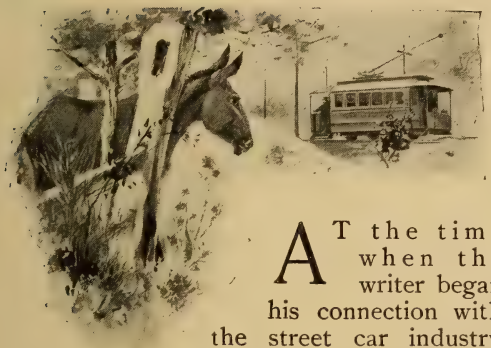
This review, then, of municipal enterprise in the working of tramways in the United Kingdom leads to the conclusion that in no single instance has it been perfectly successful. Glasgow furnishes the nearest approach to success, but in Glasgow, with a small track for an enormous dependent population, it would take very bad management, indeed, to produce financial failure. And in Glasgow the system is a very long way short of perfection, while the retention of horse-haulage renders the future exceedingly insecure. In no single instance can the municipal working of tramways be demonstrated to be a commercial success; and in no single instance has municipal management fulfilled the socialistic ideal, either in respect of its servants or its passengers.

The writer does not hesitate to say that any well-managed company, in possession of the advantages which any of these corporations whose work has been reviewed possesses, would have, long ere this, produced much better results both for itself and for the public. Nothing is said of the serious dangers and onerous charges that may await the ratepayer as the result of what Lord Wemyss calls, "the mad move of Municipalities towards the municipalisation of everything,—gas, water, tramways, in the present, and all other things in the municipal future.'

THE DEVELOPMENT OF THE STREET CAR

FROM HORSES TO ELECTRICITY

By John A. Brill



AT the time when the writer began his connection with the street car industry in 1868, the latter had reached the end of its first period of development, and for several years but few changes had been made in horse car construction. It was about this time that the industry entered upon its final period of development. The car then in use in one of the largest American cities was of the type shown in Fig. 2. It had a 16-foot body, and was very heavy in proportion to its capacity. Among its peculiar features were the raising of the windows, which were of small size, and, for the sake of increasing the light, were provided with a stationary sash above, which had circular heads fitted with fancy-figured ground glass. At each end of the roof there was the customary ventilator and a short length of ventilating sash in the centre. While seating only 22 passengers, it weighed 5700 pounds. It was neither better nor

FIG. 1.—A TRAM CAR OF FORTY YEARS AGO IN NEW YORK CITY

FIG. 2.—A FORM OF CAR USED ORIGINALLY IN PHILADELPHIA IN 1868

FIG. 3.—A 16-FOOT AMERICAN CAR BUILT IN 1870

worse than the other types found in all parts of the United States at that day.

Progress really began in 1870, when the odd-looking car gave way to the type shown in Fig. 3. Large windows replaced the smaller windows of the older car and the sash dropped instead of raised, as has been the practice ever since. In this car the lighting was better, the ventilation improved, and the weight was reduced by fully 600 pounds. Progress once having started was extremely rapid, and improvements went on in a great variety of directions.

The most striking change in car construction was introduced in 1873 from

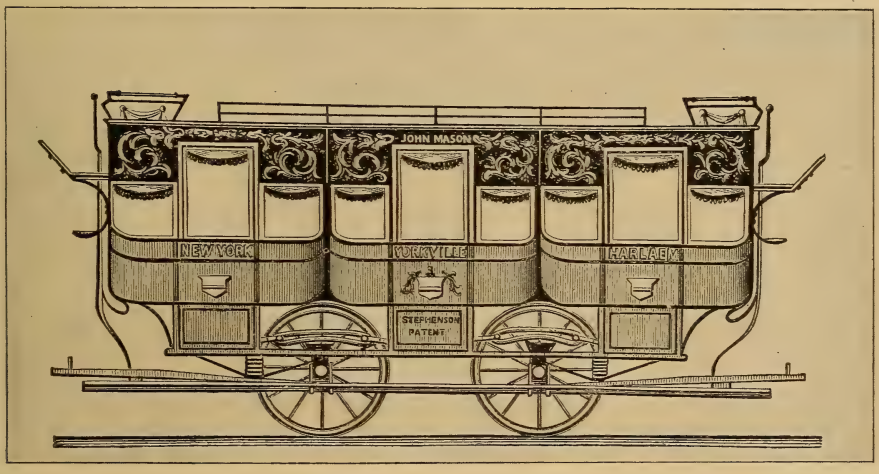


FIG. 4.—A TRAM CAR OF 1832. BUILT BY JOHN STEPHENSON, NEW YORK

steam car practice. This was the American "monitor roof," which had been in use on steam roads for nearly ten years. For some time previous the horse car roof had simply five or six small ventilators in the side. This form, however, was weak, and the central section almost invariably sagged. When the new form of roof was adopted the whole side of the raised deck was framed in one piece so that it could be supported from the ends or head pieces of the car and thus obtain a firm abutment. The cars of the new type were not only more cheerful, but the ventilation during the crowded hours was much improved. Fig. 5 represents the first car of this kind ever built. The new roof came into favour at once.

The motive power available for street car propulsion at that time was a span of horses or mules. This limited the total weight which could be carried and made every pound saved in the car a gain in carrying capacity. While this demand for great strength with a minimum of weight was seemingly an onerous burden upon the car builder, its result was altogether beneficial, for it necessitated the most careful selection of materials and the most perfect and durable construction. The weight of a 16-foot standard horse car, with a seating capacity for 22 persons, was finally brought down to 4280 pounds, and cars of this type were frequently loaded with from 75 to 90 persons. In spite of this disparity between the weight of the vehicle and its load, horse cars built in the early '70's have been in constant service up to the present day, and many of them are still running, having been utilised for electric car bodies.

To secure ease of riding as well as ease of hauling, much attention was paid to the "running gear," as it was called, and two distinct systems were in vogue. One of these guided the vertical motion of the journal box in jaws after the fashion of the steam railroad box, and braced the jaw rigidly to the car body,

FIG. 5.—THE FIRST AMERICAN HORSE CAR WITH A MONITOR ROOF. BUILT IN 1873 BY THE J. G. BRILL COMPANY, PHILADELPHIA

so that all motion except that in the vertical direction was impossible. The other system left the car body free to float, as it were, upon the springs, merely holding the journal boxes at fixed distances from each other. After years of test, the elastic connection between the body and the journals prevailed over all others and was universally adopted. Looking back upon the history of the contest between the two systems, it seems strange that the idea of the rigid connection between the boxes and the horse car body could ever have been seriously considered.

FIG. 6.—A TYPICAL HORSE CAR, 1875–80

While the reduction in car weights was going on, made necessary, as has been stated, by the limited power available in a span of horses, and while the running gear was being improved in the matter of flexibility, the attention of inventors was directed toward the reduction of friction in the bearings. Hundreds of patents were taken out for various types of roller bearings. The most successful of these in America was the "Higley box," which found much favour for eight or nine years, and then, like many other things on street railways, was abandoned because it ultimately required costly repairs.

The box itself was made up of a pair of interlocking rollers, one single and one double, which had a length of 6 inches and a diameter of 5 inches. These rollers, which had chilled faces, turned on journals. The journal of the axle, bearing against these rollers, made about three revolutions to one of the rollers, reducing the friction to about one-third. It was, in fact, a modification of the old grindstone box. Bearings of this class did all that was claimed

for them while the rollers were new and were kept in line. But when wear had once commenced, they soon got out of alignment and the friction became greater than that of a plain bearing. They finally went out of use before the abandonment of animal traction.

Shortly after the American Civil War, Mr. J. B. Slawson became interested in the street railways of the city of New Orleans, finding them in a very depressed and unprofitable condition. He gave great attention to the economies of operation, and finally conceived the idea of running a car without a conductor and using a farebox into which the passengers dropped their fares, the change being furnished by the driver. Probably no radical improvement in any line in which the public was interested was ever more universally misunderstood and condemned by the public than this innovation, which was by general consent dubbed the "bobtail" car, and its invention credited to the meanness of the street car companies. Outside of railroad men, there is probably not a person in the community who remembers them who understands the advantages which accrued to the public from their introduction.

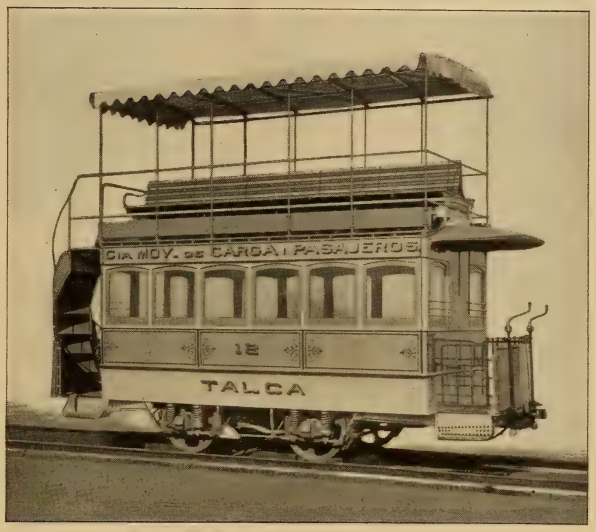


FIG. 7.—A CHILIAN DOUBLE-DECK HORSE CAR

By a reduction in the size of unit and

FIG. 8.—A SLEEPING CAR ON A SOUTH AMERICAN HORSE RAILWAY

FIG. 9.—A FIRST AND SECOND-CLASS COMPARTMENT CAR IN CHILE

the amount of power required and the halving of the crew necessary for the car, more frequent service was permitted on lines which were not paying than was possible with a span of horses and two men on a regular car. By making a short headway between cars, the system educated people to ride and greatly developed the valuable feature of short rides. It was quite as valuable for the public as for the roads, and it made many a line successful commercially which would otherwise have been obliged to give up business.

FIG. 10.—ONE FORM OF AMERICAN OPEN CAR

About 1870 the one-horse car with the fare-box was first introduced in the northern section of the United States, and in 1873 or 1874 they were to be found on almost all the lines in the country. The front end was entirely closed by the dasher, while the rear of the car was provided with a step instead of a platform. The rear door was controlled by the driver, the door-closing mechanism in some cases consisting of a rock shaft and levers and in others of an endless cord running over pulleys. This type of car, with its inclosed front end, required a turntable or loop at the terminus of the line.

Another form of fare-box car extensively used had an open platform at each end, and, in many cases, had two fare-boxes and in others a single fare-box that was carried from end to end. Just at the time when the prosperity of the roads was throwing the small fare-box car out of service, an important improvement was made in the fare-box system. This consisted of an arrangement of slides by which the passenger was enabled to put his fare in the box without leaving his seat. This overcame one of the greatest objections

which had been urged against the "bobtail" car. The new fare-box was immensely successful in developing travel on street car lines, and was abandoned only when traffic became so heavy that larger two-horse car units, with conductor and driver, were necessary.

Undoubtedly, it will be found profitable on many of the small electric lines to return to this same method of building up traffic, using, in the beginning, a small unit without a conductor and making the headway shorter, thus giving a service satisfactory both to the public and to the railway company. A large number of roads are now beginning operation and many more are in course of construction which cannot, with the so-called standard unit, by any possibility pay investments at present. Their hope for success lies in the return to this fare-box system. When the public once understands that the fare-box presents as many and perhaps more advantages for them as it does for the railway, there will probably be no further opposition to its introduction in places where it can be utilised profitably.

The horse-car industry reached its greatest development between 1875 and 1880. Many of the roads which had found themselves compelled to use the fare-box and the small car, had, by this time, grown into prosperity, and the two horse car was again the standard and most generally used type on the roads of the northern part of the United States. There were, indeed, variations to meet special requirements of service, but they were exceptional.

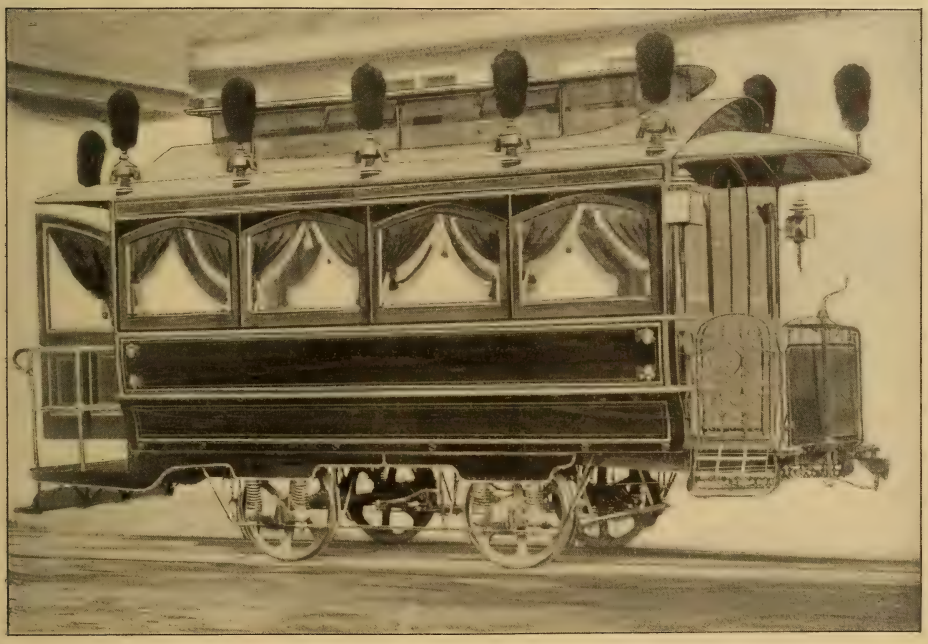


FIG. 11.—A FUNERAL HORSE-CAR USED AT BUENOS AYRES, ARGENTINE REPUBLIC

Fig. 6 may be taken as being a fair representative of the type. This was a 16-foot car body, seating 22 persons, and it weighed 4900 pounds. While these cars composed the bulk of those in use in the United States, where powerful animals were to be had in abundance, a great many modifications were built for other countries.

Fig. 7, for example, shows a double-deck horse car built for use in Chile. The upper seats were longitudinal and were covered by a canopy. The body and interior of the car were of the usual

style. This car was intended to be run in a single direction only, and had a curved stairway by which the roof was reached from the rear platform.

Fig. 8 shows one of the most remarkable horse cars ever turned out. It was for the Tramway Rural in Buenos Ayres, Argentine Republic,—a road about 90 miles in length, operated entirely by animal power. For a journey of such a length, sleeping accommodations were indispensable, and a sleeping-car for a horse railway was a necessity. The interior was so divided as to give eight berths, with the usual lavatory facilities. It may be interesting to note the fact that these cars, after being in service for many years, were utilised in a novel way when the line was reorganised and steam was substituted for mules. The new cars were mounted on double trucks and had space in the centre for the bodies of these old horse cars which are to-day thus in service as centre compartments of long sleeping-cars.

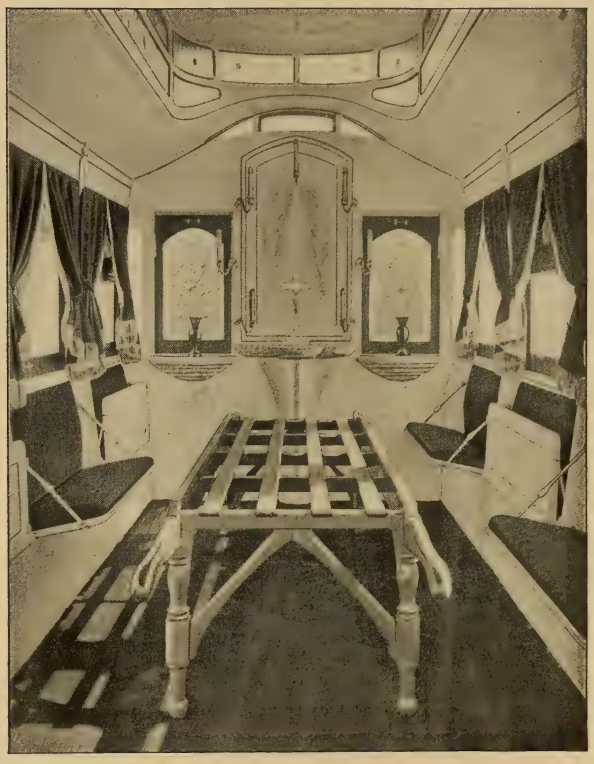


FIG. 12.—INTERIOR OF THE CAR SHOWN IN FIG. 11

Fig. 9 shows a first and second-class compartment car built for a tramway in Chile. The inclosed compartment for first-class passengers was finished in the latest modern style, while the second-class compartment in the rear was open and of the plainest description.

Fig. 10 shows a form of open car used extensively in many parts of the United States; the sides are protected by curtains in case of storms, and the seats are stationary, of the vis-à-vis type.

Figs. 11 and 12 show exterior and interior views of a first-class funeral car used in Buenos Ayres. To many the idea of a funeral car may be somewhat of a novelty, but such cars are extensively used in foreign countries, and some of the steam roads in the United States have found profitable employment for cars of the same kind. In Mexico the street railway is used as generally for funerals as hearses and carriages are elsewhere, and the specialisation of cars for this purpose in South America is simply carrying the idea to its logical conclusion. The car shown is very elegantly finished. There are also second and third class funeral cars, correspondingly less elaborate in their appointments.

Fig. 13 is an inspection car in service on the Tramway Rural of Buenos Ayres. A ladder on the side gives access to the platform on the roof. This car is fitted with what is probably the most effective life-guard ever invented. Just outside of each of the wheels is a rubber-covered wheel, suspended by a link. In ordinary use this wheel barely clears the rail. When any obstruction or person is thrown upon the track, the

FIG. 13.—A SOUTH AMERICAN INSPECTION CAR

small wheel, on striking it, is at once thrown backward against the wheel of the car, and acquires a reverse motion which lifts and throws forward the object in contact with it. Practical experience shows that it is almost impossible, if not quite so, to run over anything like a human body with this appliance. If we were asked to explain why so valuable a contrivance did not come into general use, it would be as difficult to answer as in the case of many other similar meritorious inventions.

The double-deck car shown in Fig. 14 is of a type which has been very popular in some quarters. It is very pleasant in fine weather, but the passengers on the upper deck are greatly exposed in case of storms. The principal objection to them, however, has been that they are slow, on account of the time required to get passengers from the upper deck to the platforms. No railway company seems to have had the courage to make it a rule not to stop until the passengers had reached the floor of the car. The adoption of such a rule would, undoubtedly, increase their usefulness.

For summer use an open car had been built in the early '60's by Stephenson, of New York; but for many years this type of car, now in such universal use, was but little known, and its value was even less appreciated. The original

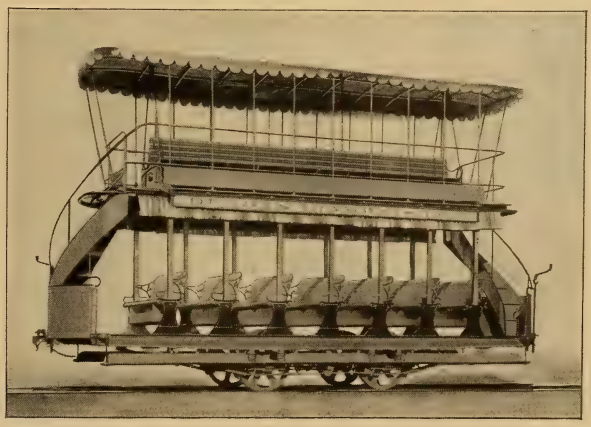


FIG. 14.—A DOUBLE-DECK CAR ON AN AFRICAN TRAMWAY

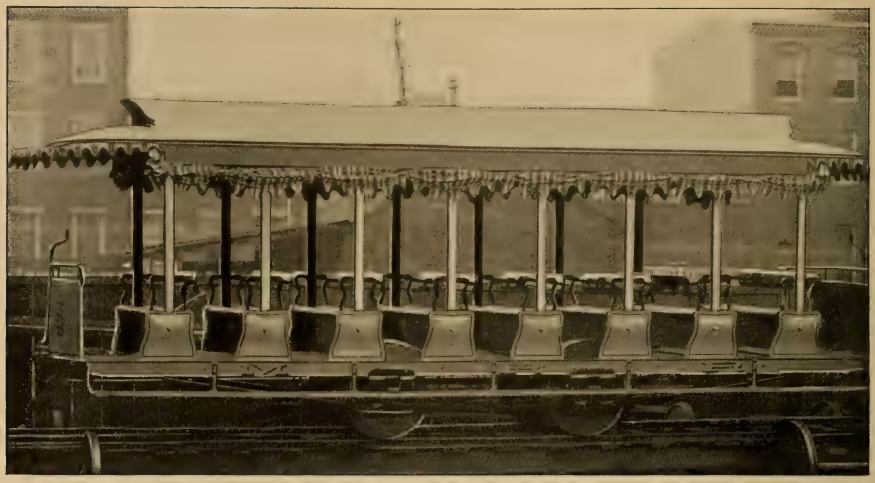


FIG. 15.—THE FIRST AMERICAN OPEN CAR WITH SEAT END PANELS

forms of open car were very primitive in every way. They were extremely plain, the backs being single pieces of board about 7 inches wide, the seats narrow and uncomfortable, and the posts or pillars plain sticks without any panels at the seat ends; altogether, the car was uninviting, uncomfortable, and weak. The roof was a plain arch of about 12 inches rise, and in many cars was covered with painted canvas, no roof boards being used. The only protection in case of rain was the curtains on the side. These could be rolled up by hand. Cars of this type were tolerable only in the pleasantest summer weather. Fig. 15 shows what was probably the first open car ever made with seat-end panels. This was a radical improvement in open-car construction, giving the naturally weak post a greater longitudinal as well as transverse stability, and also improving appearances as well as adding to the comfort and safety of the passengers. The roof, however, remained in the same primitive condition except that it had the end ventilation. It is interesting to note that with these slight improvements horse cars of this type are running at the present day, having been considered in good enough condition when the roads adopted electricity to be fitted with electric motors; and, in spite of the apparent weakness of these roofs, they have been carrying trolley boards and poles successfully for several years.

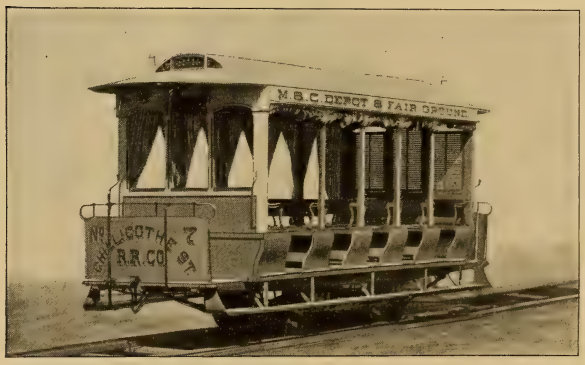


FIG. 16.—AN OPEN CAR WITH END BULKHEADS TO REDUCE RACKING

The improvement of the open car involved great mechanical difficulties. The loads to be carried were enormous in proportion to the weight of the vehicle, which, in the United States, had to be limited to 5000 pounds. Any excess over this was at the expense of the endurance of the horses, and was found, by dearly-bought experience, to be disastrous.

After the introduction of the wooden panel at the seat end, the two most important features were the introduction of a regular monitor deck with ventilators. The monitor deck, combined with the roof boards, greatly increased the stiffness of the car and reduced the racking.

In 1874 another improvement was made in the open car construction. This was the introduction of what is known as the bulkhead at the end of the car. This bulkhead, as shown in Fig. 16, consisted of a closed end, having sash and blinds, which dropped into a panel work that formed the back of the forward or outer seat. It did not differ materially in construction from the ordinary end frame of a car, and is one of the essential features of the modern open horse car. There have been, from the first, two types of open cars, namely, those with reversible seats and those in which the seats were stationary or vis-à-vis.

The next improvement in open cars was the introduction of a car with the blinds sliding into the roof. These blinds took the place of curtains and closed the side of the car. This arrangement was particularly serviceable in open cars for suburban use, the lower section serving to prevent people from falling out. But it was rather costly, and never came into general use.

The next improvement was the introduction of metal to take the place of

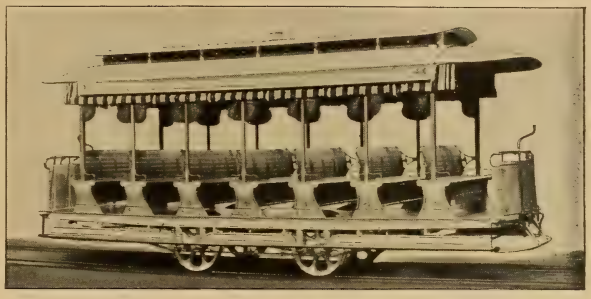


FIG. 18.—A STANDARD OPEN HORSE CAR USED IN THE UNITED STATES ABOUT 1882

the wooden panels at the seat ends. This was first introduced in 1882 in the shape of two small panels on each side of the post, as shown in Fig. 17. These metal panels were not only more durable, but added greatly to the strength of the post, and in the following year the panels were made in single pieces instead of in two, and later improvements curved their corners inward to give easy entrance to the seat. These panels enable the curtains to be drawn down to the floor, and repairs were greatly facilitated by them, as it was only a matter of an hour or so to re-

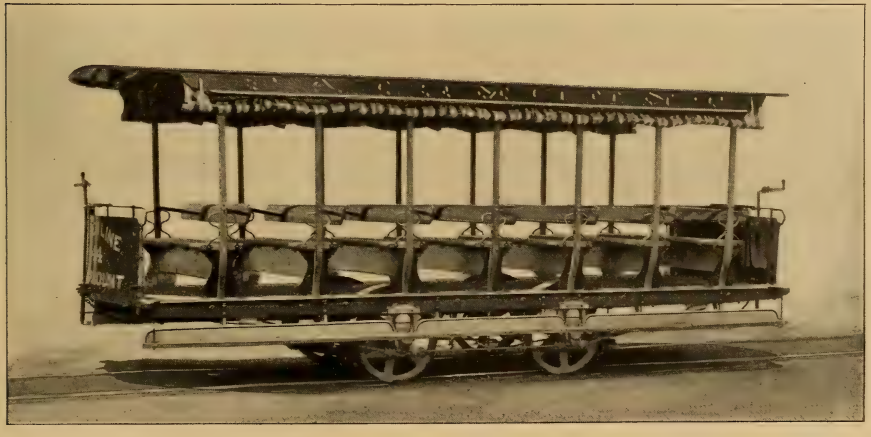


FIG. 17.—AN OPEN CAR WITH METAL SEAT END STIFFENERS

place one of these panels, which were kept in stock ready for use in case of accident.

Fig. 18 shows a standard open horse car of that period. It had a seating capacity of thirty-five passengers, and was capable of carrying as heavy a load as was practicable for a team of horses. The power of animals varied greatly in different countries, and some of the mule teams used in foreign countries must have been of insignificant strength, as a six-bench open car for the city of Manila, in the Philippine islands, shipped from the United States, weighed but 2900 pounds. Special cars for all sorts of purposes were built for use on street railways, including chicken cars, live sheep cars, meat cars, freight cars, and gravel cars.

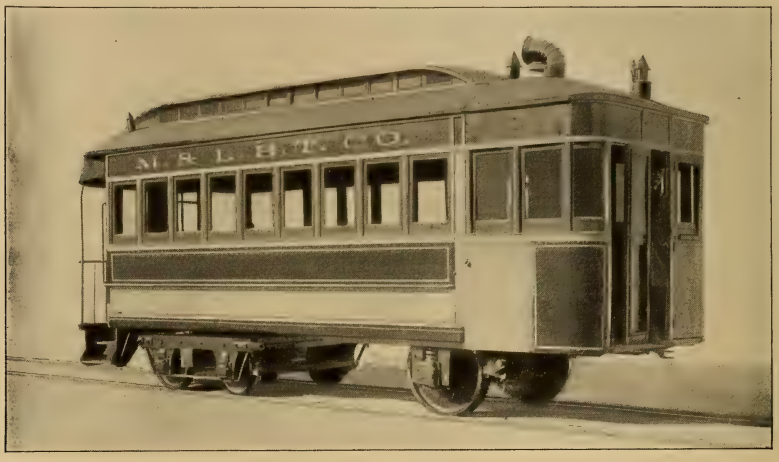


FIG. 19.—AN AMERICAN STEAM MOTOR CAR, 1865

POWER ON STREET RAILWAYS.

From the earliest days of street railways, the subject of mechanical propulsion was agitated, and was taken up with a great deal of interest both by street railway men and inventors. Numerous attempts have been made to introduce steam motors on the streets. Notably among these in the United States was that made on the Second Avenue Line in the city of New York. The motors were apparently successful, in spite of the very light track. The directors of the company were so impressed that the whole line was re-laid with heavier rails, and the economy over horses appeared to be undoubted until repairs to the motors began to be needed. These became so excessive that the further use of steam was abandoned, and the owners of the road returned to horses.

Later, Messrs. Grice & Long, car builders, at Trenton, N. J., took up the subject. Between the years 1865 and 1870 they made a variety of separate motors and also of motors and cars combined, and had numbers of them distributed in all parts of the United States. So far as can be learned they were all discarded, except those on the Frankford and Southwark Passenger Railway in Philadelphia. This road operated the suburban end of their street railway from Philadelphia to Frankford with dummy cars and trailers.

One of these is shown in Fig. 19. These dummies were regularly employed up to 1893, when electricity was introduced upon the road. They had an engine in the forward compartment of the car, which, by means of a countershaft and gearing, drove a pair of wheels beneath. The rear end of the dummy was carried by a radial swinging four-wheeled pivotal truck. The

dummy, during the busy hours of the morning and evening, hauled a double-deck trailer, a particularly interesting feature, which, so far as the writer knows, was unique. This dummy line was probably the most successful one in the United States, and the only one which ran double-deck cars through a series of years. The grades were steep and the speed was very high. Motor cars built by the Gilbert-Bush Company and propelled by a Ransom engine, were run in the city of Philadelphia in 1876 during the time of the Centennial Exhibition. Later, the J. G. Brill Company, of Philadelphia, built a number of motor-car bodies for the Baldwin Locomotive Works, and also one for a motor car designed by L. T. Pyott.

This car was remarkable for having embodied in it many of the fundamental principles necessary in the construction of electric cars. It contained the essential feature of journalling the motor to the driving axle in such a way that while the motor was spring-carried, its distance and relation to the centre of

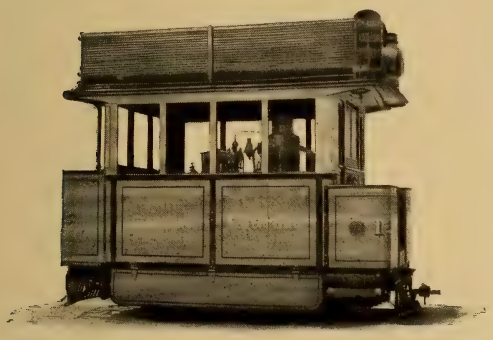


FIG. 21.—A STEAM DUMMY WITHOUT PASSENGER ACCOMMODATIONS

the driving axle remained fixed. This feature was found absolutely essential in hanging motors on electric trucks.

The Baldwin Locomotive Works, of Philadelphia, Pa., were building steam motors for street roads as long ago as 1873 or 1874, and have probably done as much, and perhaps more, than any other establishment in the United States towards the introduction of steam upon the street and suburban railways. It will be a matter of surprise, even to those who are familiar with the subject, to know that, at the present time, there are in the United States 75 lines operated by steam dummies. But at the time when electricity was introduced, they were in practical use on about twenty different American street car lines in the Southern States.

FIG. 20.—A COMBINATION STEAM MOTOR CAR WITH CONDENSER ON ROOF. BUILT BY THE BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA

In mentioning the history of steam motors it is necessary, in order to understand why they were not more generally introduced, to speak of the prejudice people had twenty years ago in favour of horses. The horse was looked upon as the fundamental element in city transportation. Whether it was the pavement or the street car that was brought up for discussion, the requirements of the horse were the deciding elements in the minds of the public. Smooth pavements were out of the question, because the horse would not have as good a footing as upon the Belgian block. A steam motor, or a car propelled without horses by any sort of a motor, was utterly condemned in the minds of the public because "it would frighten horses." For the same reason elevated roads were opposed most vigorously by people of all classes, because of the scare which the horses would receive. The talk about the horses served its purpose and delayed

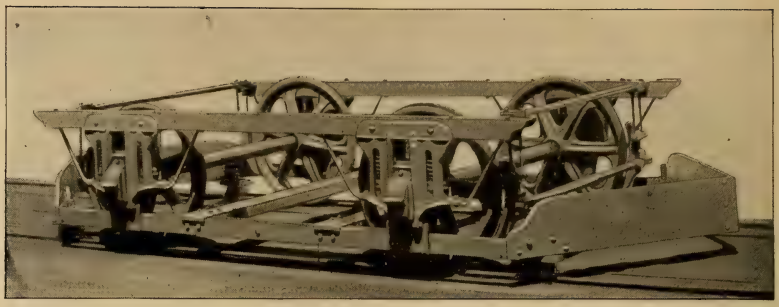


FIG. 22.—THE FIRST OF THE MODERN CAR TRUCKS

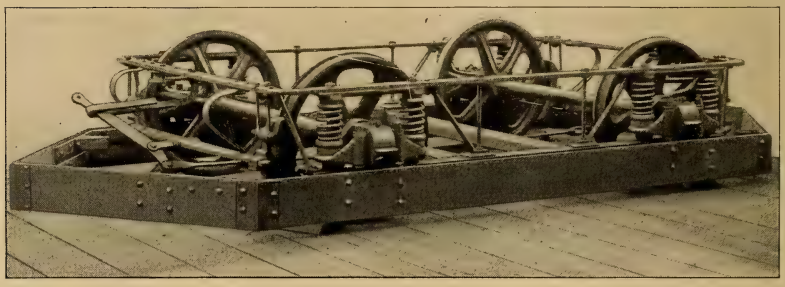


FIG. 23.—THE NEXT STEP. A GOOD TRUCK FOR SHORT CARS

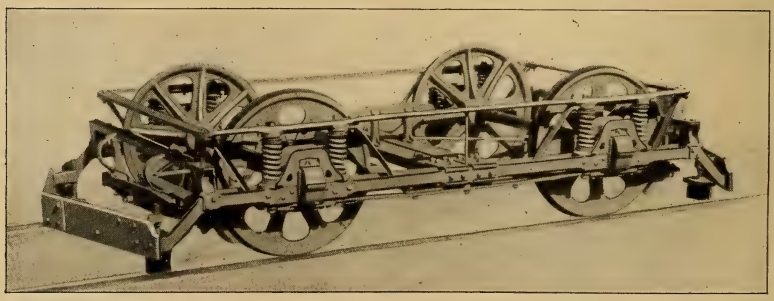


FIG. 24.—A TRUCK INTENDED FOR LONGER CARS

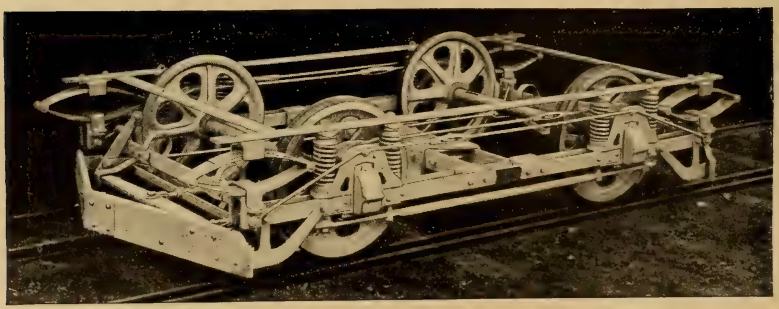


FIG. 25.—A STILL LATER AND BETTER TYPE

the adoption of improved motive power on street railways for many years.

Steam dummies had two different forms; in the first, the dummy was combined with a passenger compartment; in the other, it was independent. Fig. 20 shows the combination type. The motor is one of the latest type built recently by the Baldwin Locomotive Works, of Philadelphia. The motor consists of a compound engine driving a four-wheeled truck. The cylinders are 6½ × 9 inches, with 12-inch stroke. The drivers are 30 inches in diameter, the wheel base of the driving truck is 5 feet, and the total wheel base is 19 feet 6 inches. The rear truck is of the ordinary equalised type, with half-elliptic springs combined with the spirals.

There are three compartments in this car, one for the engine and boilers, one for baggage, and one for passengers. Steam pressure of 180 pounds is used, and the public's plea against anything that will frighten horses is disposed of by the application of a surface condenser in the roof through which the steam is distributed when running through city streets in order to prevent its escape into the air.

Fig. 21 shows a motor built without accommodations for passengers. It is very short, takes the whole weight on the driving wheels, and, as in the other case, has a surface condenser to prevent the escape of steam. The engine is compound and direct-connected. A successfully used modified type of the first of these dummies is where the engine and car body are carried upon four wheels only. The machinery is usually covered by apron boards hung to the car body, which hide the side rods in all positions.

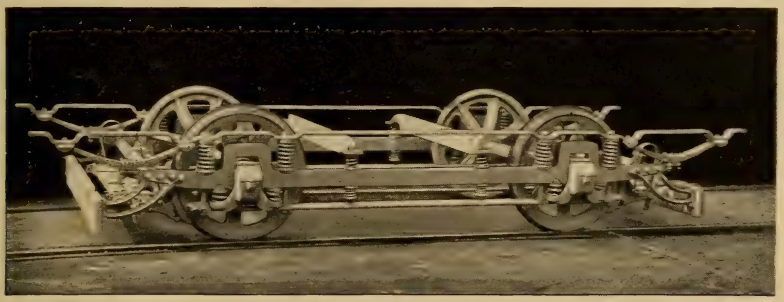


FIG. 26.—A TYPICAL MODERN TRUCK

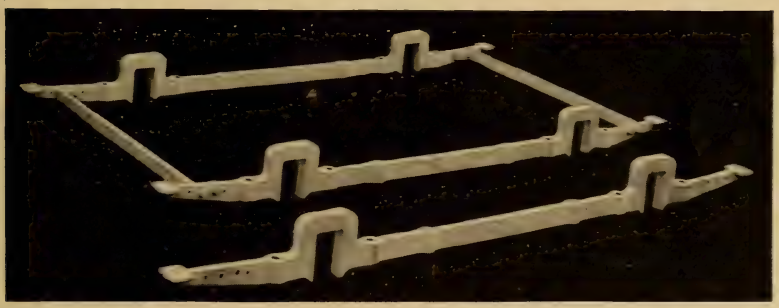


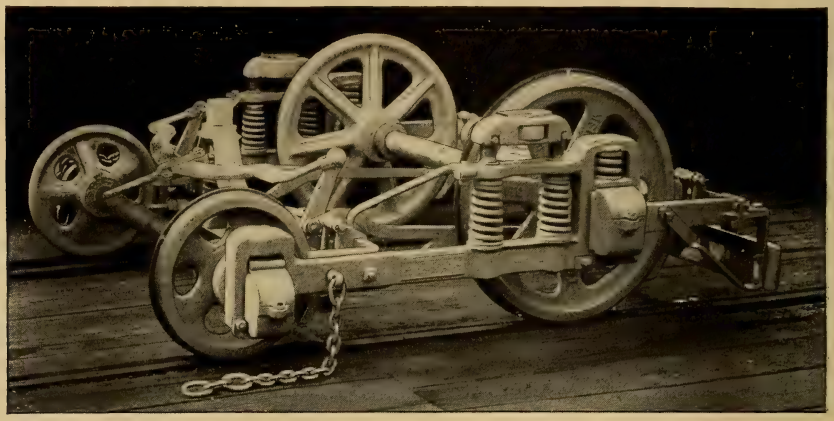
FIG. 27.—THE TRUCK FRAME ALONE

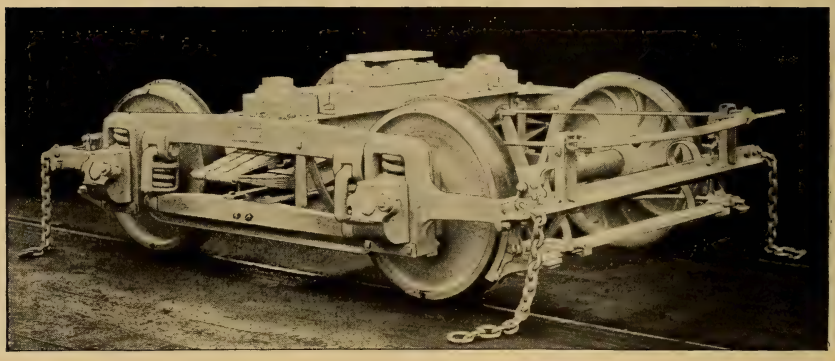
CABLE TRACTION.

For a time cable traction appeared to be the coming system upon street railways. Its great success in several large cities made it appear to most engineers as likely to hold the field against all other systems. It was first put in oper-

ation in San Francisco in 1873 by Andrew S. Hallidie. While to him belongs the credit of having put the idea into practical operation and secured for it commercial success as a means of street car propulsion, the essentials of the system were suggested before by E. S. Gardiner, of Philadelphia. Cable traction and cable haulage were not new of construction. Although the cable road of the future will probably be confined to grades which cannot be worked by adhesion, the grip car still has some points of interest.

The first cable railway in Chicago began operation in 1878 and the grips were carried on short, open cars. The gripman stood in the centre of the car





FIGS. 28 AND 29.—TRUCKS FOR EIGHT-WHEELED CARS. MADE BY THE J. G. BRILL COMPANY, PHILADELPHIA

ideas, however. They had been employed in various forms in European mines, and the Blackpool tunnel, in London, had been worked by cable for some time before this.

The grip car was a novelty in street car construction, and its details have had a certain influence upon the electric car of the present time. The "trailers" were usually large horse cars pure and simple, and presented no novelties and the gripping device was operated by a system of levers. In the California cars with double trucks the grip was carried forward of the bolsters. This location not only caused the grips to wear out quickly, but the slot rails on curves were cut with great rapidity. In 1884 the first cable railway was put down in Philadelphia. There were numerous failures before the road was put in successful operation, but that re-

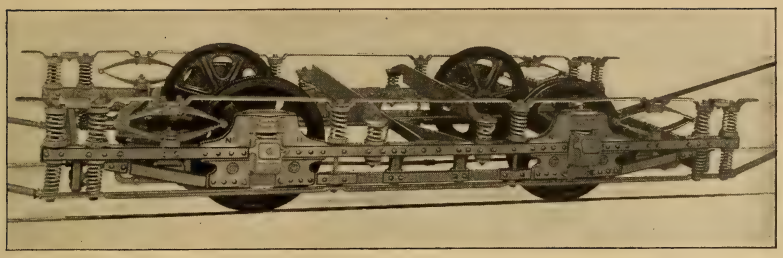


FIG. 30.—A STANDARD TRUCK MADE BY THE PECKHAM MOTOR TRUCK & WHEEL CO., KINGSTON, N. Y., U. S. A.

sult was finally obtained by carrying the grip on a frame which was mechanically the equivalent of the modern axle box frame. In Philadelphia on the long cars the grip was placed in the centre of the truck, thus reducing the swing upon the curves. This was accomplished by the novel expedient of an open bolster. One of these features had some influence in the development of the modern electric car, and is, therefore, historically interesting.

ELECTRICITY.

In the early '80's, when it was first strongly proposed to propel street cars by electricity, few, if any, of the promoters had any idea that considerable changes would have to be made in the construction of horse cars to adapt them to the new service. It appears to have been one of the theories of some of the electrical engineers that electricity as a motive power could be applied to the ordinary horse car. In many cases electric motors were placed on platforms, and, as might have been expected, soon destroyed both the platform and the car itself. Motors were attached to the car body and managed to quickly shake the whole structure to pieces. Only after several failures to

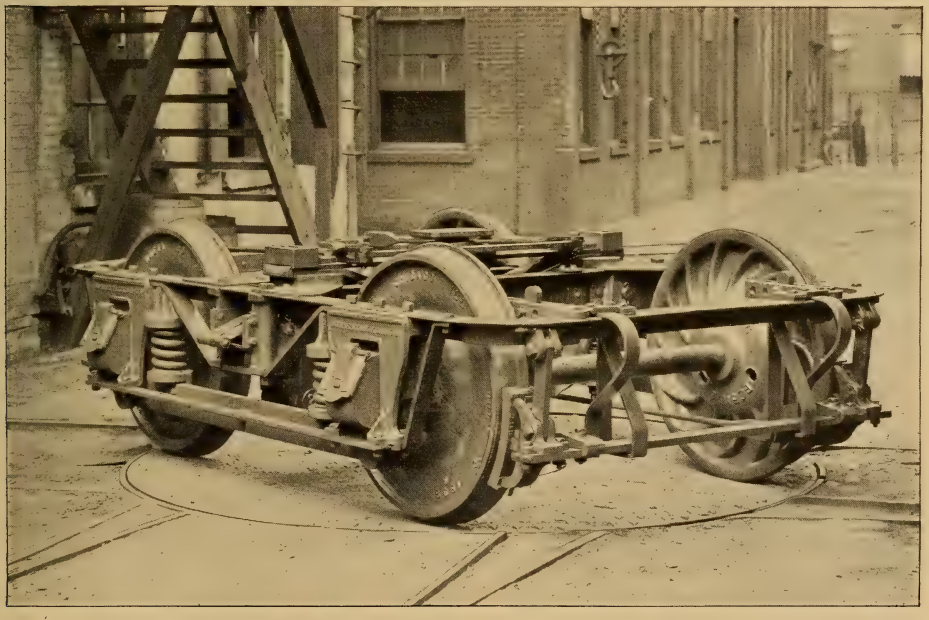


FIG. 31.—A TRUCK MADE BY THE DORNER TRUCK & MFG. CO., CLEVELAND, OHIO, U. S. A.

turn a car structure into a locomotive was the fact recognised that a new element must be introduced, and that a car body could not successfully be operated as a locomotive frame, and that it springs, the car body, and in itself resisted all the strains of the driving mechanism. The writer was the inventor and first constructor of a truck modelled on these lines for four-wheeled

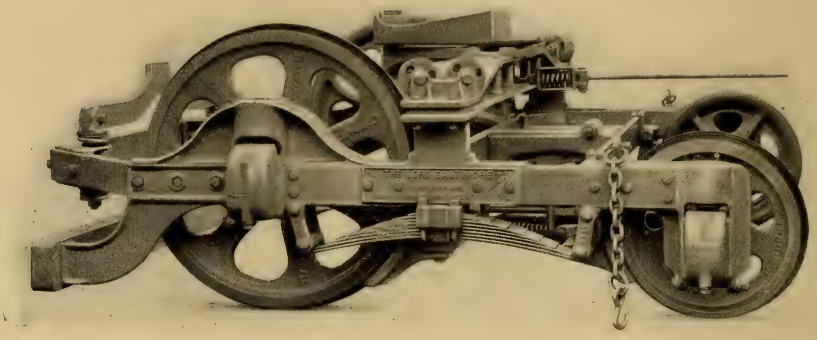


FIG. 32.—THE LORD BALTIMORE MAXIMUM TRACTION TRUCK, MADE BY THE BALTIMORE CAR WHEEL CO., BALTIMORE, U. S. A.

was unable to support the heavy and rapidly revolving machinery.

Several systems for transmitting the power to the axle were tried, and the first step in the right direction was made by Mr. F. J. Sprague, who placed the motor on the axle and hung the other end to the car body. This, however, did not go far enough. The fact was soon recognised that the electrical machinery should be entirely independent of the car body, and upon the introduction of the feature of a separate truck one end of the motor was hung on the axle and the other end on the axle-box frame. This system affords a locomotive which, in addition to carrying the motive power, also carries the car body as an independent structure. This invention of the separate truck for four-wheeled cars was of great importance, and it is difficult to see how the street railway in its modern form would have been possible without it.

The modern truck may be defined as a carriage, supported on a set of springs, which carried, independently, the motive power, and, by another set of electric cars. The feature of the four-wheeled truck was not at first accepted as a necessity, but several years of costly experiment proved that it was a necessity. The stern logic of facts forced the idea into the minds of street railway men, and it is to-day universally accepted. When the idea of the separate truck had once been received, the success of electricity as a motive power was no longer doubtful.

FIG. 33.—CAR NO. 30 OF THE BUFFALO & NIAGARA FALLS RAILWAY

Fig. 22 represents the first truck of the kind ever constructed. Its fundamental feature was the support of the machinery by a rigid independent frame, which contained an upper chord or connecting frame for carrying the car body and relieving the latter entirely from

the strain set up by the driving machinery. It was not at first seen that the fundamental principles of locomotive construction should be as closely followed as in the case of the heaviest express engines. This idea, in fact, is hardly yet thoroughly understood, and the railway world is going through the same absurd experiments with the frame work of its electric trucks that were made from thirty to fifty years ago in locomotive practice.

The first line of ideas followed out in the development of the truck frame is shown in Fig. 23. A continuous upper chord of flat bar iron was used, from which a system of trusses was extended downward so as to give the proper support to the machinery. This frame, considered statically, was all that could be desired. It was light, strong in vertical direction, and gave the machinery ample support. Eight springs held the journal boxes, and converted the truck into an easy-riding carriage. It was, however, adapted only to comparatively short cars, while an increase was demanded in the size of the unit for the sake of economy. Plunging or galloping with the short wheel-base was inevitable.

For the purpose of carrying the over-hanging ends of long cars and making repairs easier, the type shown in Fig. 24 was devised. This consists of malleable iron jaws, which form the foundations of the frame, into which are riveted or bolted flat parallel bars forming the frame itself. The upper chord, by means of diagonals, is converted into a truss to take the strains away from the car body.

The type, however, did not meet the requirements of the long, overhanging car body, and was again modified, as shown in Fig. 25. Here truss rods were introduced to hold up the springs, which were placed on the extreme ends of the extended frame. The fundamental fault of this frame was the same as that of the built-up locomotive frame. Rivets, bolts, and a multitude of parts will, in spite of the most careful workmanship, part company. In an electric car this is found to be a more serious objection than it is in a locomotive, for, in addition to letting the machinery get out of line, its parts make an intolerable noise

FIG. 34.—A STANDARD AMERICAN TYPE OF TO-DAY. A 20-FOOT CLOSED CAR

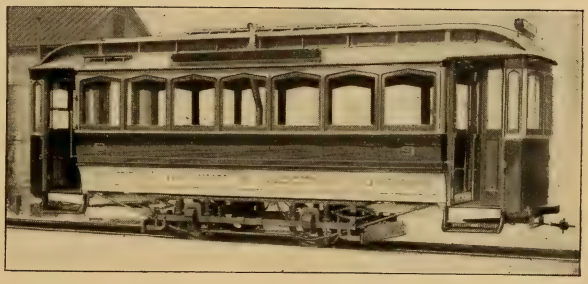


FIG. 35.—THE SAME CAR WITH VESTIBULES

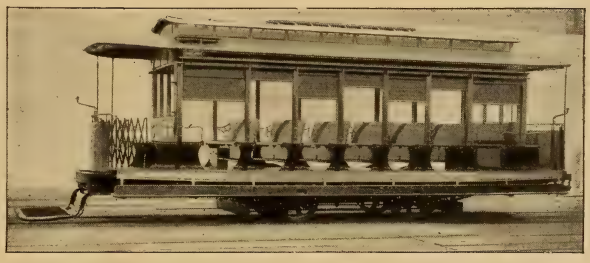


FIG. 36.—THE CORRESPONDING STANDARD OPEN CAR

when in motion. The electric car, at its best, is a noisy affair, and an addition to the noises which cannot be avoided is a source of endless complaint.

While trucks of this kind are still in operation, and many of them doing good service, they require constant attention, and are always liable to give trouble. Their popularity with builders of trucks comes from the fact that they can be built rapidly and require only inexpensive and ordinary machinery and workmen for their construction. Bar iron, cut off to fixed lengths and pounded into simple forms, is easy to handle; if rivets are employed, a riveting machine sets them with great rapidity. The truss, too, takes a strong hold on the minds of the managers of street railways, who very frequently have little knowledge of the requirements.

The frames just illustrated are the types upon which nearly all the built-up trucks of the present day have been modelled. Modifications of details have been made, but the fundamental principles are unchanged. Unfortunately, they are radically wrong.

The American locomotive frame, after having gone through all the modifications of plates, riveting and combinations of wood and iron, has finally settled down to a system of wrought iron bars of nearly rectangular section. The strains in a locomotive or motor truck are not only vertical, but also lateral and longitudinal. They constantly change their direction and intensity when the machinery is in motion. Practice and theory combine in choosing the solid rectangular bar frame as the most economical and effective form for resisting such strains. As the vertical strains from the load usually exceed the others, the vertical dimension is made greater than the horizontal. All things considered, this gives the best and most economical form for the frame to carry the machinery.

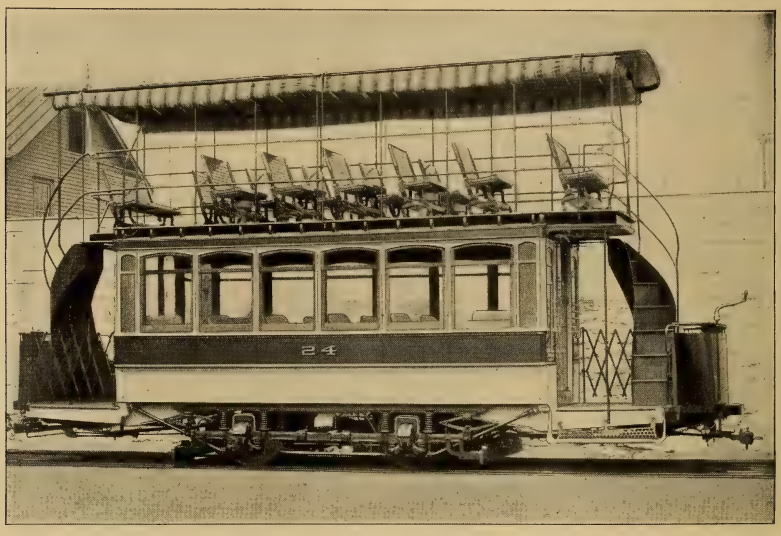


FIG. 37.—A MODERN DOUBLE-DECK CAR

In the earliest frame of this type the axle-boxes are held by jaws formed in a wrought-iron bar. The extension pieces are forked at each end and carry the springs which support the ends of the car body. The two side frames are connected by cross-bars secured to side posts. This frame has finally been modified into the form shown in Fig. 26. The frame alone is a forging such as shown in Fig. 27.

The functions of a truck are peculiar and exacting, and those of the four-wheeled truck seem almost in defiance

to the laws of motion. In passing over the smoothest rail, we find irregularities of greater or less size. The function of the truck is, therefore, to hold the machinery in perfect alignment, to be carried forward over the rails without permitting its alignment to be disturbed, and without transmitting the shocks received from the irregularities of the track to the machinery. In a word, it must be a perfect locomotive.

At the same time, it is necessary to carry the car body also in such a way as to prevent it from receiving strains from the revolving mechanism beneath it or shocks from the irregularities of the track. When carrying a car body with long, overhanging ends, it must prevent this body from pitching or galloping. All these things can be accomplished within limits, and have been accomplished in the truck shown in Fig. 26, by employing eight journal springs, mounted on the ears of the box itself. These carry the whole weight, including the frame and machinery. Above the frame there are eight more springs, spirals on each side of the journal boxes, and half-elliptic springs on the ends of the extension pieces. These springs have the peculiar characteristic of overcoming any regular motion that may be set up. They utterly refuse to vibrate, and, having once yielded to a blow, return at once to their normal condition without a repetition of flexure.

Theoretically, the motors should be supported at their centre of gravity, on springs, and should have link connections to the axles so that the centre of the pinion should always be in a line concentric with the gear wheel. No weight whatever should be carried directly on the axle. This is not usually accomplished in practice, and a considerable portion of the weight comes upon

FIG. 38.—A COMBINATION BAGGAGE AND PASSENGER CAR

FIG. 39.—A CALIFORNIA TYPE OF COMBINATION CLOSED AND OPEN CAR

FIG. 40.—A CONVERTIBLE CAR BUILT BY THE DUPLEX CAR CO., NEW YORK

the axle, which should be carried from the side bars of the frame by springs both beneath and above it, so as to give an elastic upward and downward motion.

The length of the wheel-base, or the distance between the points at which the wheels touch the rails, has usually been a disputed question. To prevent galloping, a long wheel-base is required, while to make traction easy on curves there should be a short one. As only about 7 per cent. of any ordinary street railway line consists of curves, and as galloping is exceedingly destructive to a straight track, common sense teaches that it is better to have a car pull a little hard around a curve and run easily and without doing damage on a straight track.

A limit is soon reached in the length of four-wheeled cars beyond which the galloping or plunging is so great as to make it impossible to maintain even the heaviest track in good condition under them. At 10 or 15 miles per hour, cars weighing only 18,000 or 20,000 pounds rapidly destroy track laid in the most substantial manner, and it is a matter of common knowledge that electric street railway tracks are as substantial as those of the best steam railroads. As the hammering of the large cars goes on, its results increase in a seemingly geometrical ratio, and after a couple of years the road becomes rough and irregular. It is useless to think of a reduction in weight or size of the unit as a remedy, because economy of operation with heavy traffic makes a large car indispensable. The alternative seems to be eight-wheeled cars.

With two motors an eight-wheeled car is found to have an insufficient amount of adhesion for fast city service, and to put in four motors involves double the expense for maintenance. To meet these conditions, a truck was invented by the writer which completely filled the requirements then. It is shown in Fig. 28. Its essential feature is the eccentric distribution of the load on the wheels. The truck has a solid steel frame, a pair of large driving-wheels, and a pair of small or pony wheels for guiding. The whole centre of the truck is open for the reception of a motor of the largest size. The normal weight distribution is such that 80 per cent. comes on the driving-wheels and 20 per cent. on the pony

wheels. Something over one-quarter of the total load is necessary for the guiding wheels when the car is rounding a curve, while 20 per cent. is ample on tangents. The necessary increase of the load is effected automatically, and variations of this load, if necessary, can be effected quickly and easily.

Many complicated conditions are involved in the construction of a truck of this character. For example, the large wheels must come high up between the floor timbers on the car in order to bring the car body down as low as a car mounted on four wheels. The small wheels, having a large amount of swing, must clear the timbers and steps of the cars. In passing, it may be noted that, for very heavy traffic in cities, the step of the car should be as low as that of a four-wheeled car, in order to give easy access to the platforms; otherwise, the time for taking on and distributing passengers is increased, and the mileage greatly lowered.

It was at one time thought that a six-wheeled truck, or, rather, a combination of three two-wheeled trucks beneath a car, would be the best solution of the problem of long cars for heavy traffic. A great deal of money has been spent in this line, but radical weakness is found in the impossibility to equalise the centre wheels with those at the ends in such a way as to prevent the small wheels from shouldering the load. As the small wheel has to have about 30 per cent. of the weight for guidance on curves, no method has yet been devised to prevent it from taking even the whole weight of the car when passing over a sharp summit like that of the approach to a bridge. The truck of the type shown in Fig. 28, however, has solved the double-truck problem in a satisfactory manner. Such trucks can run at a high rate of speed and prevent entirely the objectionable galloping of the car body.

FIG. 41.—A DUPLEX CAR INTERIOR

City, suburban, and interurban traffic

FIG. 42.—A CONVERTIBLE CAR BUILT BY THE J. G. BRILL COMPANY, PHILADELPHIA

FIG. 43.—THE CAR WITH SIDES OPEN

FIG. 44.—AN INTERIOR VIEW SHOWING ONE SIDE CLOSED, WITH TWO OF THE CURTAINS PARTLY DRAWN, AND THE OTHER SIDE OPEN

usually call for a practice more closely approaching that of the steam railroad than that of any other street railway service. The cars must be long, in order to carry the large number of passengers; they must frequently be provided with smoking and baggage compartments; and they must run at speeds which may reach 50 or 60 miles an hour. To meet the demands of this service a variety of trucks have been devised. One of the most notable of these is shown in Fig. 29.

The history of this truck's introduction is one of the most interesting things in street railways. It was built by the writer's company in 1895, and a pair was put under a car running between Buffalo and Niagara Falls. In placing it in service the express stipulation was made that it was on trial, and, if unsatisfactory, would be replaced with another truck without cost to the railway company. Nothing was heard of it for a month after it went into service, when the motorman and conductors reported that people along the line would wait for the appearance of the car mounted upon these trucks because it rode much more easily than any of the other cars. Its fame rapidly spread through the city of Buffalo and along the line. In three months' time car "No. 30" was known to every conductor and motorman in the city. This car is shown in Fig. 33. It may be added that ultimately the road was equipped throughout with the new form of truck.

The peculiar features of a truck for an eight-wheeled car are not easily explained to laymen, nor even to the professional railway man; they seemingly involve mechanical impossibilities. A truck should be a three-legged stool, although it has four wheels; that is, the load should be so distributed to the wheels that each one may be elevated or depressed to a considerable distance, say, 1 inch or 2 inches, without altering the relative weight which each wheel carries. Under such conditions the ordinary truck would have the weight upon only two of the wheels. The theoretical truck, however, passes over the irregular surface of a railway track with its wheels conforming accurately to the rails, while it carries the car body in a plane parallel to the track, and the motion in the wheels is not transmitted to the body. In passing into or out of curves, and in meeting with any of the horizontal deviations from a straight line, found even in the best laid rails, the truck can move up, down or sidewise without moving the body.

These complex features are obtained by means of equalisation and "swinging beams." The equalisation is effected by connecting points near the journal boxes by means of a beam or lever and practically placing the weight in the centre of this lever or equalising bar. This bar is seen in Fig. 29, supported at each end by links containing springs.

The "side motion" is mechanically equivalent to carrying the whole body of the car suspended by links from the truck. This is accomplished by allowing the car body to rest upon a central transverse bolster in the centre of the truck. This bolster is held between a pair of transoms which permit it to take a lengthwise motion across the truck. It is supported upon springs, and, with the equalising bars and the spring plank (on which the body springs rest), constitute the "swing motion." With this construction the truck can move with considerable freedom without taking the body with it. This relieves the flanges of the wheels from the shocks which the vis inertia of the body would otherwise throw upon them.

The perfectly equal distribution of the load on the wheels and the absence of shocks to the flanges, even when entering curves at high speeds, combine to make this form of truck remarkably safe. It seems to be almost impossible to make it "jump the track."

The successful introduction of the system of electric traction made a radical change in street car construction. In the cities it was at once seen that a large car could be used with advantage, since an increase in the size of the unit diminished the proportionate cost of

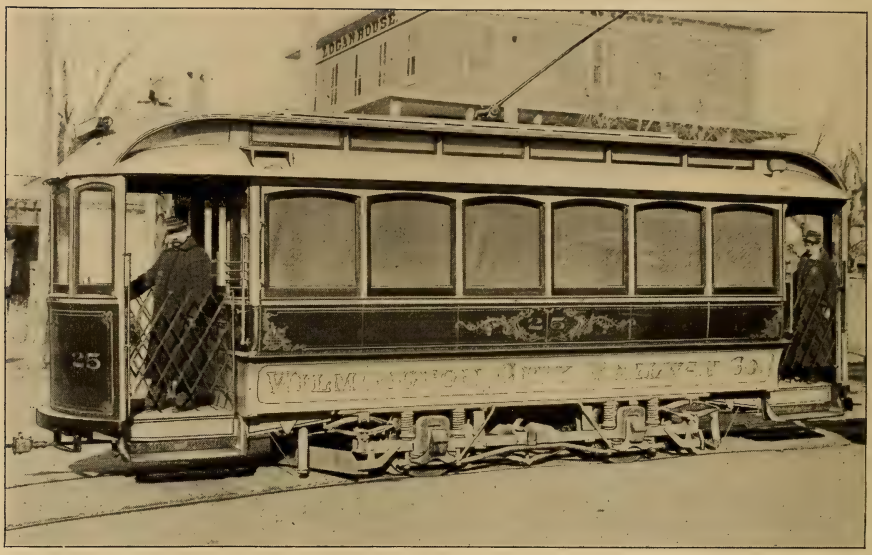


FIG 45.—A CAR BUILT BY THE JACKSON & SHARP CO., WILMINGTON, DEL., U. S. A.

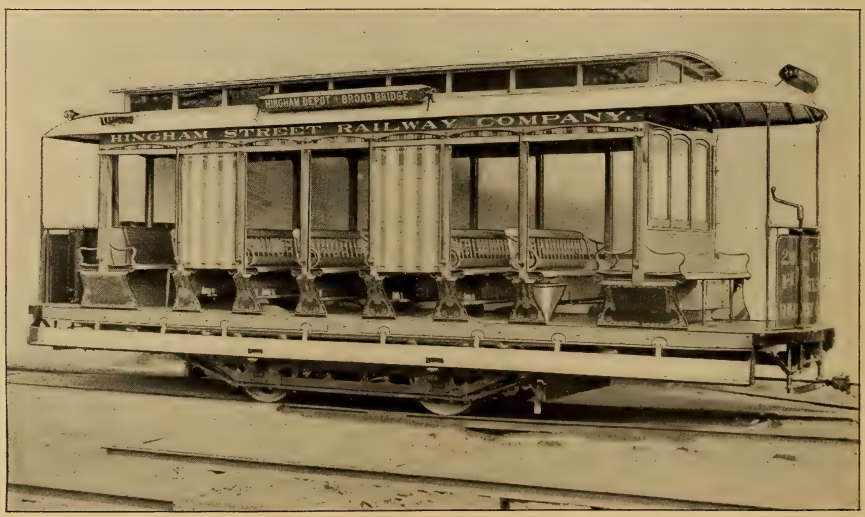


FIG. 46.—AN OPEN CAR FROM THE SAME BUILDERS

FIG. 47.—A CAR BUILT BY THE AMERICAN CAR COMPANY, ST. LOUIS, MO., U. S. A.

wages, while the cost of hauling did not perceptibly increase.

While many of the horse-car features were retained, the unlimited motive power available made numerous improvements practicable which had been out of the question before. At the present time the standard American type is an 18-foot or 20-foot body on four wheels, with two platforms, as shown in Fig. 34. The platforms are closed by gates, and, in general, the car has the appearance of the old horse-car body enlarged. It is considerably heavier, and internal trusses are introduced to strengthen it. For the protection of motormen, conductors and passengers the platforms are frequently inclosed with vestibules, as shown in Fig. 35. These vestibules are made in the form of frames, and sometimes they inclose the platforms by having doors at the sides; in some cases the vestibules merely form a screen over the dasher. The interior finish is rich or plain, according to the fancy of the railroad company. The seats are longitudinal almost without exception.

While this is the standard type and length, the bodies are built anywhere from 18 feet upwards. An 18-foot car seats 26 persons. The corresponding standard type of open car is shown in Fig. 36. This car has ten seats or

FIG. 48.—INTERURBAN CAR BUILT BY THE BARNEY & SMITH CAR COMPANY, DAYTON, OHIO, U. S. A.

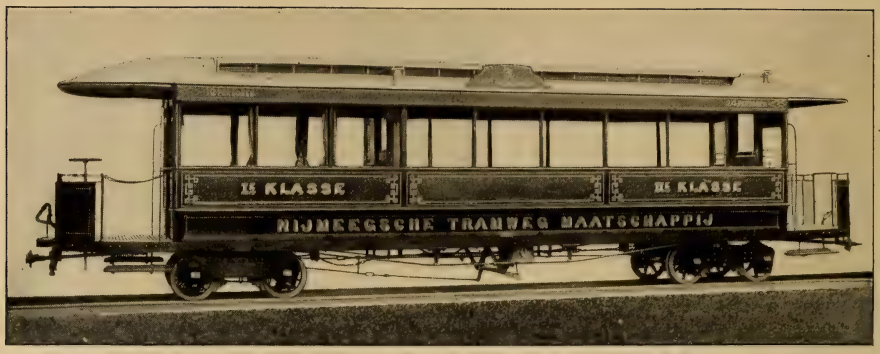


FIG. 49.—A FIRST AND SECOND-CLASS COMPARTMENT CAR, BUILT BY THE BRUSH ELECTRICAL ENGINEERING CO., LTD., LONDON

benches, six of which have reversible backs; at each end of the car there is a bulkhead between the two end seats, which are back to back. This bulkhead is furnished with a sash which can be raised in inclement weather. Side curtains and spring rollers are provided which can be drawn all the way to the floor,—an improvement which is made possible by the use of the iron seat panels with round ends. When the curtains of a car of this description are drawn to the floor, the rain is almost completely excluded, as in an ordinary closed car. The large seating capacity, usually for 50 passengers, makes them great favourites with railroad managers, while at the same time they are much liked by passengers.

The best known departures from the standard form are the double-deck cars. These are provided with either longi-

FIG. 50.—A TYPICAL GERMAN CAR. BUILT BY MESSRS. SIEMENS & HALSKE, BERLIN

tudinal or cross seats on the roof, which is reached by circular stairways at one or both ends. An example of this type mounted on four wheels is shown in Fig. 37. Cars are built for Great Britain and Continental countries without the canopy over the upper deck. While the load on the roof throws a great strain upon the body of the car, the most important disadvantage, previously mentioned, is that passengers require a long time to dismount from the roof seats.

With the advent of rapid transit by electricity there has come a demand along suburban lines for cars for hauling freight, baggage and parcels, and the mails, and this has led to the construction of combination baggage and passenger cars. A four-wheeled car of this type is shown in Fig. 38. A car, like that shown, has a seating capacity for 13 persons, while the baggage compartment occupies one-third of the length of the car.

A type of car which originated in the Western part of the United States is known as a combination car of the California type. One of the earliest of these was built by the Brownell Car Company, of St. Louis, and seems to have been the most satisfactory car of the kind which has been put in service. Its one fault was that the platforms or open ends were unusually high, and consequently considerable time was taken by passengers in entering and leaving. The recent modification, shown in Fig. 39, entirely obviates this disadvantage and brings the platform down as low as

FIG. 51.—ON THE INCLINE OF THE ELECTRIC RACK RAILWAY AT BARMEN, GERMANY. EQUIPPED BY MESSRS. SIEMENS & HALSKE

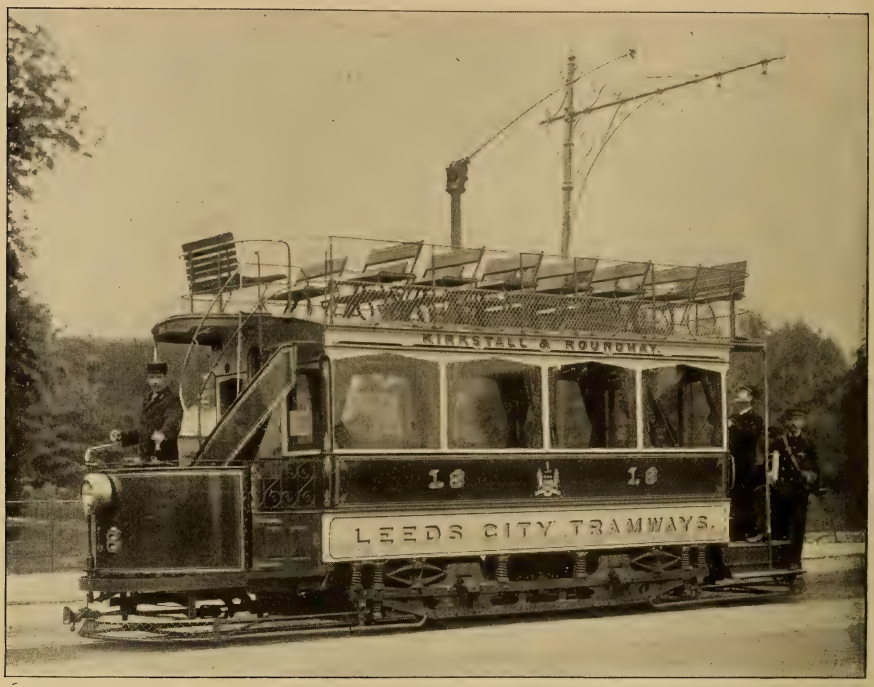


FIG. 52.—A CAR OF THE LEEDS CITY TRAMWAYS, ENGLAND. EQUIPPED BY MESSRS. GREENWOOD & BATLEY, LTD., LEEDS

those of an ordinary open car. The body seats 18 passengers; there is a platform at each end upon which two seats are placed, giving a seating capacity of 20 persons. Between the backs of the-cross seats there is a bulkhead with a sash, so that, in case of inclement weather, the sash may be raised, side curtains drawn to the floor, and all except the two end seats completely inclosed. The seats on the platforms are placed longitudinally in some cases. The strengthening of the platform is accomplished by means of angle-iron subsills, which take the whole load of the platform and entirely relieve the body of the car from strain.

As the traffic becomes heavier, and longer car bodies are necessary, four-wheeled cars give place to those with double trucks, and as a result many new types of car bodies come into use. In some cases even the steam railroad type is introduced, and we have the straight sides and high platforms, reached by several steps.

The reader will naturally expect an illustration and description of the car which fully meets the needs of street railways,—in a word, one which fills all the requirements. The writer feels somewhat diffident in presenting and describing such a type to the readers of this magazine, because he is the inventor of one of the two cars for which this claim has been made. To deserve the name, it must fill the wants of the railway men and at the same time satisfy the public. The ideal car, from the railway standpoint, is one of the convertible type, which can be used at all seasons of the year and for every service. It must be arranged in such a manner as to be agreeable alike to women, and to men who smoke. For long-distance runs transverse seats are desirable, but these are at the expense of standing room. For short runs, longitudinal seats are best, in which case the standing room is at the maximum. As it is the "standing load" that pays, this is a most desirable feature.

The problem is still further compli-

cated by other demands or needs of the public, which, in addition to the points noted, wants a car suited to the weather. In winter it must be closed and warm, and in summer entirely open. But when open it must admit of being easily and quickly closed, and when closed, as quickly and easily opened. The car will not be satisfactory unless it can readily conform to the requirements of a climate fickle at all seasons of the year.

An incredible number of convertible cars have been built in the effort to obtain a design which will combine all these features. They are to be found in the car barns of nearly every large railway company.

Up to the time when the cars shown

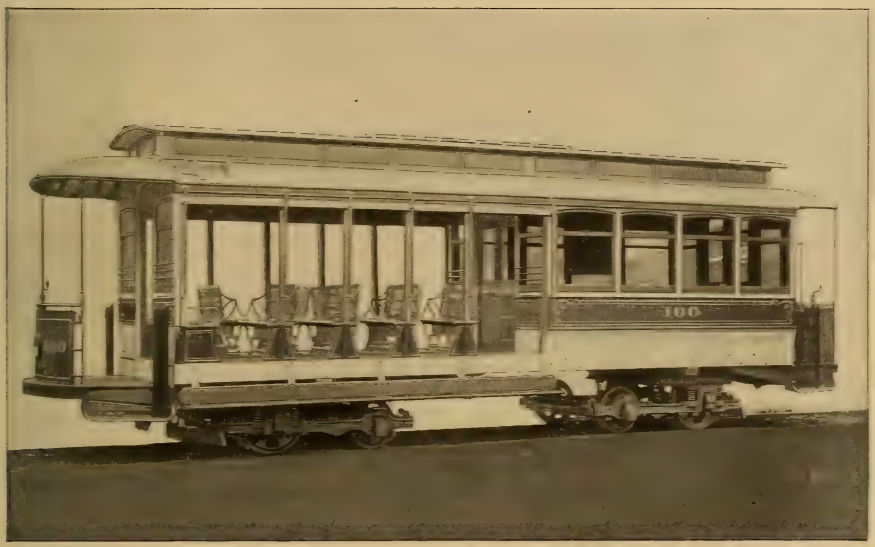


FIG. 53.—A COMBINATION CLOSED AND OPEN CAR, BUILT BY THE LACLEDE CAR CO., ST. LOUIS, MO., U. S. A.

FIG. 54.—A CAR FOR SUBURBAN SERVICE BY THE SAME BUILDERS

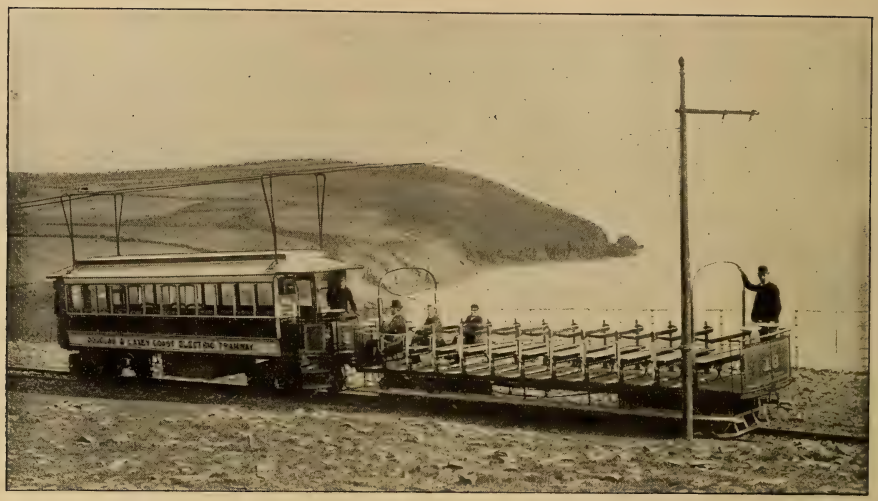


FIG. 55.—MOTOR AND TRAILER CARS ON THE DOUGLAS & LAXEY COAST ELECTRIC RAILWAY, ISLE OF MAN, BUILT BY MESSRS. MATHER & PLATT, LTD., MANCHESTER, ENGLAND

FIG. 56.—ANOTHER VIEW SHOWING THE TRAILER CAR FITTED UP WITH A ROOF

in Figs. 40 to 44 were introduced, none had reached or even approached the ideal. Some fatal defect had made itself manifest in every case, and with each new type the reluctant verdict was pronounced, that the car of the future was yet to be built. In Figs. 40 and 41 are presented views of the "Duplex" car.

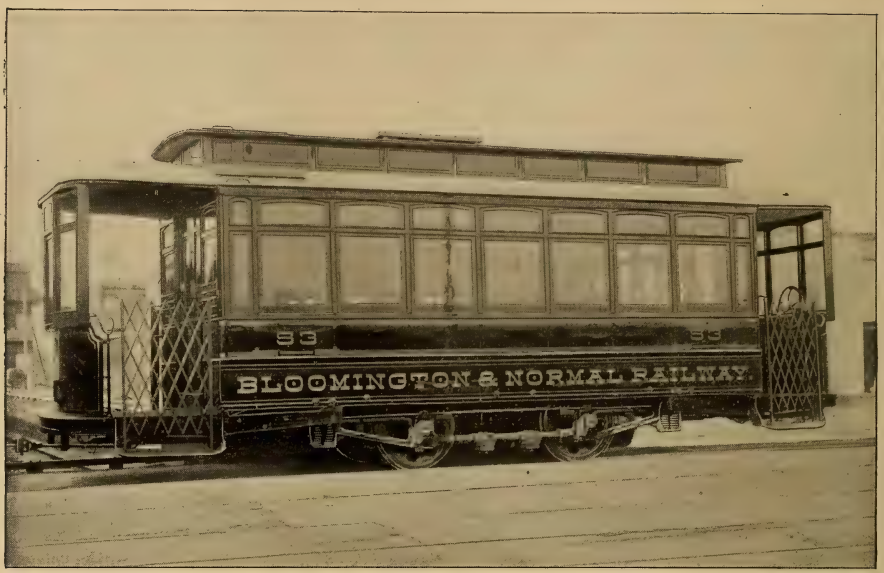
As will be seen, this car is intended to give all the advantages of both the open and closed types, and, like that of the writer, to meet the conditions which have just been named as being essential to the car which fully satisfies the wants

FIG. 57.—A CAR FOR SUBURBAN SERVICE BUILT BY THE JEWETT CAR CO., JEWETT, OHIO. U. S. A.

of both the public and the street railway man. The leading features are continuous posts having from an end view a horse-shoe or circular outline. This enables the side panels, with the sash, glass, and curtains, to be slid in grooves into the roof of the car, leaving the sides entirely open. This work can be easily and quickly done so that the car is not only self-contained, but quickly convertible. It has cross-seats, with an aisle in the centre. The latter feature is, of course, necessary because the car when closed cannot be entered from the sides.

In appearance the car is not very different from the ordinary types, except when seen from, or near, the end, when the greater width at the upper part becomes noticeable. This, under many conditions, is somewhat objectionable. The shape makes it necessary to use curved glass, which is, unfortunately, expensive, and the form of the car and the method of construction make it rather costly to build. It should be added that whether open or closed, the car interior is by no means unpleasant, in this respect differing very much from many of the convertible cars which have passed into oblivion. The sections overlap in the roof and fill up the monitor or open part of the roof.

Figs. 42, 43 and 44 show the convertible car invented by the writer. Its form is identical with that of the ordinary car, the exterior outline of the posts differing in no way from those of the standard closed car. The open car is an open car pure and simple, with cross-seats and a centre aisle. No one, except an expert, would, from the exterior, note any difference between this and an ordinary open car. The interior view presents a few differences, notably that the curve of the roof is a



FIGS. 58 AND 59.—CARS FOR CITY AND SUBURBAN SERVICE BUILT BY THE ST. LOUIS CAR CO., ST. LOUIS, MO., U. S. A.

little higher and longer, but this would probably escape the attention of the ordinary observer.

The interior view, Fig. 44, shows the car with one side closed and two of the curtains partly down and the other side entirely open. As in the previous car, there are both curtains, glass sash and sliding panels. The panels in this case are solid, with a smooth exterior surface of oxidised metal to correspond with any colour scheme. They are, however, elastic, and are thus enabled not only to pass the grooves in the straight portions of the posts, but also into the curves of the roof.

The use of bent sash and glass is avoided by hinging the sash at the meeting rail. In this car and the one just described, the curtains, of course, present no difficulties. From this description it will be seen that the car is entirely self-contained, and that the question of conversion is one of merely

a few minutes; closing the whole car requires no greater expenditure of time and labour than would be needed for putting down the same number of windows.

The cost of construction is not materially enhanced, and by making the outside end of each seat round a peculiar form of double-curved iron panels at the end is possible. These panels support and form braces to the posts and thus materially increase the strength of the car. This form of posts enables the curtains themselves to be carried to the floor when the car is used for summer purposes, and thus gives a complete protection to the seat from sudden rain. It is available to the passenger with no more trouble than the ordinary summer car curtain, and it may be added that the mechanism for sliding the different panels, sashes, and curtains into the roof is simple and seems likely to stand the wear and tear of service. This type of car was used successfully through the fall of last year and the past winter, and proved to be as warm as the ordinary closed car.

Although the cross-seat is not as convenient for entrance and exit when the car is closed, and, therefore, not as well adapted to short rides as the longitudinal seat, yet when used as an open car the aisle with the end entrance become distinct advantages, both as to convenience and speed. This one objection to the convertible type and departure from the theoretically perfect car seems, therefore, to be a small matter.

A whole book might be easily filled with descriptions and illustrations of modern electric cars. Most of the large manufacturers have been called upon at different times to design some for special and interesting service. There are, therefore, numerous types, each one of which has been developed to meet a specific demand. Fig. 45 shows a standard four-wheeled electric car with vestibules, and Fig. 46 is a modern ten-bench open car. The closed car has what is known as a steam car hood; that is to say, the monitor roof is carried forward and dropped down so as to form a part of the hood itself.

The car shown in Fig. 47 belongs to a type largely used in the western part of the United States. The distinctive feature is a body having a very low side, consisting of a single panel, and the windows consequently come nearly to the floor. When the sash is removed a practically open car is obtained, as shown in the illustration. When the sashes are in place, a closed car results, in every respect as comfortable as those built specially for winter service. There is an opening on one side only of each platform. This opening is closed by gates which are controlled by means of a rod and lever by the motorman. Complete safety is in this way assured, since it is impossible to board or leave the car except when the gates are opened. If the motorman rigidly adheres to the rule which requires the car to be brought to a full stop before a passenger enters or leaves, there is the least possible opportunity for accident.

Fig. 48 shows a car mounted on double trucks fitted with swing beams and equalisers. The trucks in all their essential features are similar to the standard trucks on steam roads. The car is entered by steps at the diagonally opposite sides of the platforms, there being three risers at each platform. Steam car truss rods are used, and the platforms are entirely inclosed.

Fig. 49 shows a British-built electric car, furnished by the Brush Electrical Engineering Company, Limited. It is intended for both first and second-class passengers, and for this purpose is divided by a bulkhead near one end. The body has the double curved panels of the ordinary street cars, but the length is considerable, and apparently no attempt is made to strengthen it by the panelling, an iron or steel floor frame supplying the necessary strength in connection with truss rods.

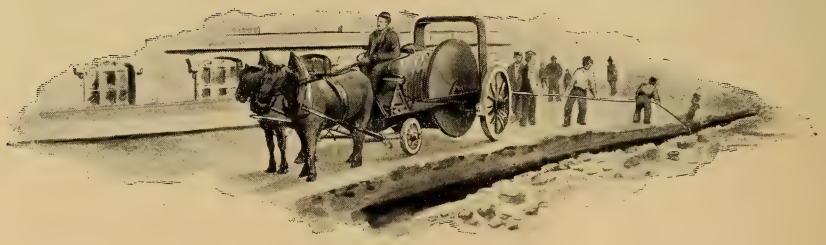
Fig. 50 illustrates a German design by Messrs. Siemens & Halske. The roof in this case is peculiarly flat, and the trolley pole, which is of the bow type without a rotating wheel, is carried by a separate frame work. The details of the car are not unusual, except that at the platform gates the entrance is much

narrower than the width of the platform. This, with the square ends, makes a platform of unusual shape. Another car by the same firm is shown in Fig. 51. This is used on the incline of the electric rack railway at Barmen, Germany. Here the body panels are curved, and, as in the previous instance, the trolley poles are apparently carried independently from the posts.

The car of the Leeds city tramways, Fig. 52, was built and equipped by Messrs. Greenwood & Batley, Ltd. It is a favourite type in Great Britain. Cars of this style never gained a foothold in America, the chief reason probably being the inherent slowness of the double deck. This car has stationary sashes and a stairway at each platform.

Messrs. Mather & Platt, Ltd., have furnished the rolling stock for an electric railway on the Isle of Man, among others, and, on account of the very peculiar styles which they have developed, their cars are of considerable interest. Fig. 55 shows one of the closed cars for the Douglas & Laxey Coast electric tramway drawing an open trailer. The motor car is of a tolerably familiar type, although the steps at one corner of the platform with two risers are a somewhat unusual feature. The trailer is not, as might be at first supposed, a freight car with low sides. Another view of the train is shown in Fig. 56, where the trailer is seen with its peculiar seats. They have apparently reversible backs consisting of a single strip of metal or wood. Both cars are mounted on double trucks having plate frames.

Four posts are added on each side of the car, and a light roof is placed over all. There are no provisions for curtains, and the car is evidently designed with the intention of making it as completely open as possible. At each seat end opening there is a hook which extends from one seat to another so as to enable the openings to be closed on occasion. The framing of the car is of channel iron, well reinforced by truss rods.



RAILS AND RAIL JOINTS

By M. K. Bowen

THE fundamental principles upon which were based the original calculations in determining the most economical manner of transporting coal from the mines in Northumberland and Durham to the docks along the rivers Tyne and Wear, in England, in the latter part of the seventeenth century, still constitute one of the greatest economic questions in railroad building in the latter part of the nineteenth century, namely, a smooth surface over which can be hauled heavily loaded trucks with the least possible energy.

In the early construction the rails were made of wood, with a flange on the outside to keep the wheels from leaving the track, and over this roadway four-wheeled trucks were drawn by horses. It was established that over a roadway thus built one horse could haul 4700 pounds, whereas over the ordinary country roads of the time a load of 1900 pounds was excessive. It will, therefore, be seen that with the advent of the new method of road building the hauling power of the horse was increased two and one half times over what it had previously been, which commensurately decreased the expense incident to hauling produce from one point to another.

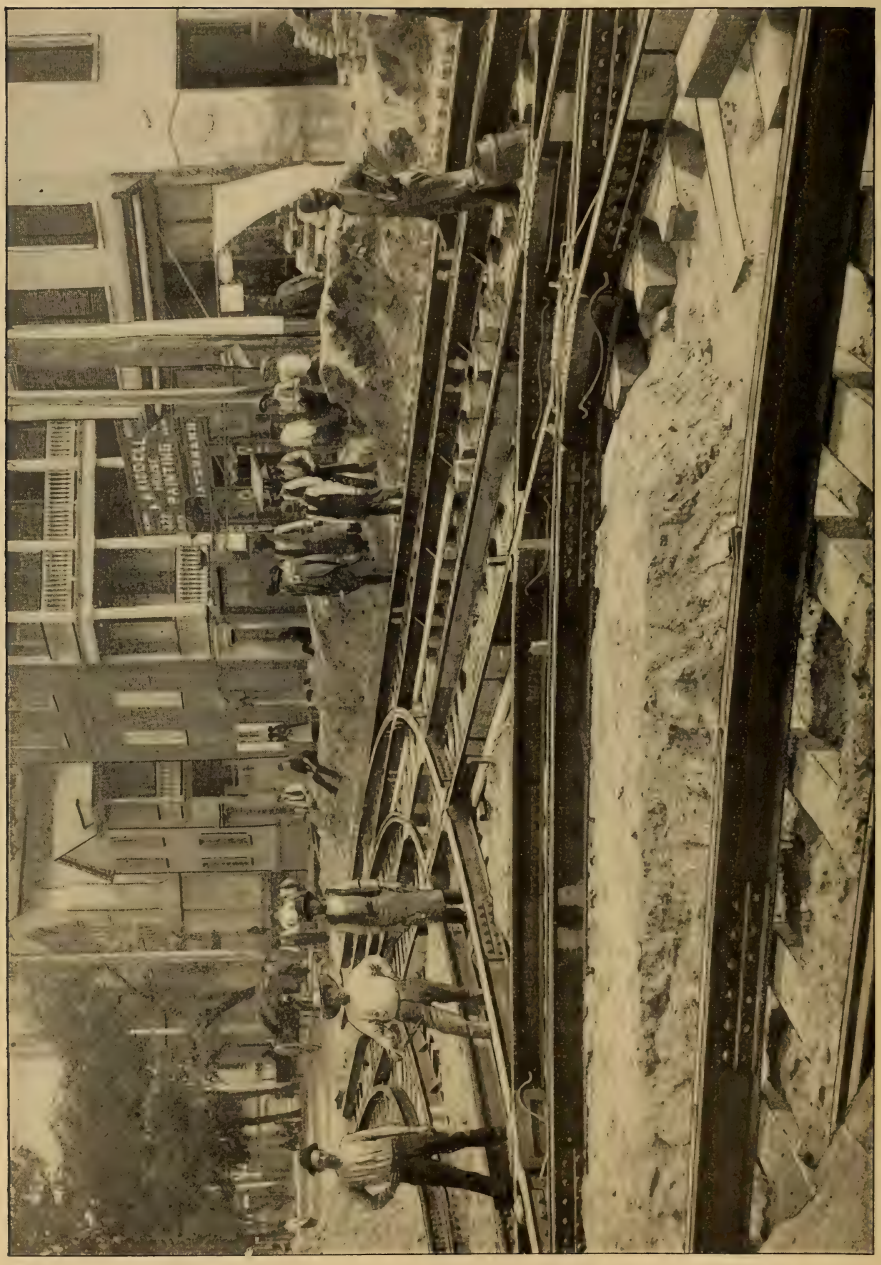
From this primitive manner of road building have been developed the smooth steel roadways of the present day. However, the progress attained has not been accomplished without a great deal of hard work, many experiments, great expenditures of money, and incessant thought; but it might be said without prejudice to the eminent engineers of the eighteenth and first part of the nineteenth centuries, that more has been accomplished towards perfecting tramway construction during the past twenty years than was accomplished during all time previous to that period.

Wooden rails remained in use for more than sixty years before iron was introduced, and it was not until 1738 that iron was first considered a factor in railway construction. Wooden strips had proved too soft to stand the wear and tear to which they were subjected by the heavy trucks, and in the above-named year cast iron strips, 5 feet long, 4 inches wide and 1¾ inches thick, were brought out near Whitehaven, England. These were spiked to the wooden strips then in use.

Not until the year 1786 did iron become very generally used in railway construction, and even then it was confined to roadway construction in the vicinity of the mines to facilitate the haulage of coal and iron. Flagstones and granite were used for sleepers in the early times, but proved too rigid and uneven to give good service, and were subsequently displaced with wood.

The great number of joints, rough track and excessive cost of maintenance occasioned by the use of the 5-foot rails, or iron strips, rendered it imperative that a longer rail be substituted, and in the year 1808 wrought iron was first introduced in the making of rails. It began to be universally used in 1820.

Great Britain having originated the idea of the common cast iron rail strips, laid on sleepers of wood, it remained for America to perfect a rail for tramways which would withstand the heavy traffic of city thoroughfares, and in the year 1877 the Cambria Iron Company,



SOME TYPICAL AMERICAN STREET RAILWAY WORK

of Johnstown, Pa., rolled the rail shown in Fig. 1. This was an innovation in two respects, being not only the first girder, but also the first steel, rail ever rolled for tramway service. It was first used in San Francisco, and proved to be strong and durable.

In the invention of the girder rail the great problem of providing a smooth and serviceable joint made a remarkable stride towards a solution, as fish-plates could be applied on both sides of the rail, making a more rigid connection than had formerly been practical. Cast-iron chairs, spiked to wooden ties, laid 3 feet centre to centre, displaced the old wooden sleepers that had been in general use for considerably over a hundred years.

FIG. 1

Subsequently, but not long after, the first grooved rail was rolled. Its use, however, was very limited. It possessed the advantage of discouraging teamsters from using the track, as the wheels of vehicles could not be kept on the rails, and this resulted in very materially reducing the number of blockades to cars and thereby facilitated traffic to an inestimable degree.

As a disadvantage, however, it was found that the groove filled up with dirt and ice and was not only much more expensive to keep clean, but, by the slipping of the wheels of the car, traction was greatly reduced and necessitated a heavy increase in the amount of power required to operate the cars. Another objection to the adoption of the grooved rail is the ease and frequency with which cars are derailed by pieces of metal, wood, or other obstruction getting into the groove.

Notwithstanding these objections, that form of rail is now being more universally used than at any previous time, and innumerable different types are being rolled by the steel mills, which conform to as many different ideas of street railway managers with a view of eliminating the most important objections as regards its adaptability to street railway conditions and requirements.

A comparison of Fig. 2, the pattern laid by the Brooklyn Heights Railroad Company over the New York and Brooklyn Bridge, with Fig. 3, that in use by the Third Avenue Line, in New York City, shows the different dimensions of the groove, Fig. 2 showing the latest pattern.

The heavy trucks, sometimes pulled by from four to eight horses in cities, contribute more toward wear and tear, spreading and general destruction of rails than is possible by the operation of 6 and 8-ton electric motor cars, and were it permissible to lay a rail which would discourage teamsters from using the track of street railway companies to facilitate easy haulage of their over-loaded waggons, the expense of maintenance of tracks would be very greatly reduced. However, the flanges of rails may differ materially without affecting traction to any perceptible degree, and it makes little difference what legislation prescribes in the manner of a flange so long as it does not attempt to dictate the specifications after which the ball of the rail is to be rolled.

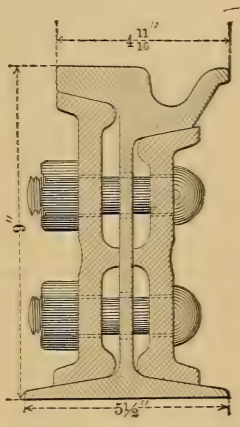


FIG. 2

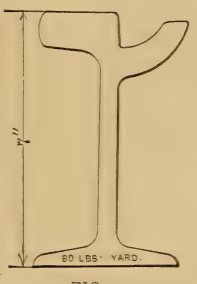


FIG. 3

In order to fully appreciate the significance of this very important part of the rail where the car wheel gets its bearing, let us for a moment analyse what experience has demonstrated to be the proper-shaped ball for a girder rail. Street car wheels are made conical

AN EXAMPLE OF CURVE CONSTRUCTION

or beveled instead of flat, for the purpose of centering the car on the track and for providing a means for a lagging wheel to catch up, thus maintaining the axles of the car at right angles with the rail. On a quarter-circle curve of 50 feet radius the outside wheel is compelled to travel 3 feet 8¼ inches farther than the inside wheel, and the absurdity of the bevel of ¼ inch on a 2-inch tread compensating for this travel and preventing slipping is readily apparent as, if the outside wheel had a diameter of 30 inches the inside wheel would have to run on a diameter of 28⅝ inches in order to compensate for the difference in length of travel of the wheels.

FIG. 4

Fig. 4 shows a section of the rail now in use on a cable line in Chicago, the height of the head being 1 3-16 inch. The first rail laid on that road had a head ¾ inch high; this was increased to an inch, and later to 1 3-16 inch; it is beveled to conform with the bevel of the car wheel for two-thirds of its section from the gauge line across the head.

No doubt there is a slipping of the wheels on the rails, due to the varying diameter of the wheel at all points. Imagine the wheel divided into three circular parts, Fig. 5, and each piece free to move by itself. It is quite evident that as the portion *a* makes one revolution, it will travel over a shorter distance than the portion *b*; and, similarly, the portion *b* will travel less far than the portion *c* in one revolution. But on account of the wheel being all in one piece, the portion *a* travels farther than it otherwise would, thereby causing it to slip; and the portion *c* travels a less distance than it otherwise would, thereby causing it also to slip. This is based on the supposition that the car would move a distance equal to

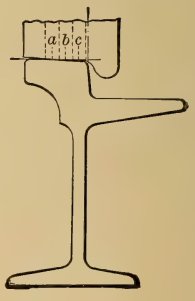


FIG. 5

the circumference of the wheel at the point *b* in one revolution of the wheel.

The waste of power due to slipping is very slight, for, considering the coefficient of friction as 0.15, it is found that for a ton-mile the energy lost by slipping is 0.0104 H. P.,—so small, in fact, that it may be ignored. The experience of the Chicago City Railway Company, who first tried the form of head shown in Fig. 4, has been that it saved wear of both rails and wheels, increasing their life by about 35 per cent. Why not, in building a track, put in rails which are beveled to conform to that of the car wheel at the outset, and not spend time and money wearing the wheel and rail down to conform to each other?

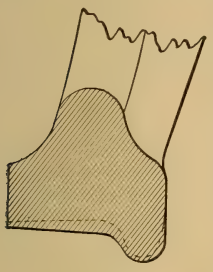


FIG. 6

Fig. 6 shows a section of a new and an old car wheel, and demonstrates clearly the manner in which the tread of the wheel will wear if used on a rail with no bevel. The record of car miles of this wheel is not known, but no doubt a great amount of energy was lost before it had worn down to its most economical state. Fig. 7 shows a rail taken out after eight years' wear, during which time 8,000,000 car wheels passed over it. Fig 8 shows a rail which was taken out after eleven years' service. The rail should have been taken out three years previous, but owing to other contingencies the track was not rebuilt. The true rate of wear cannot be found, as the flange of the wheel had begun to run on the flange of the rail long before it was removed. The dotted lines indicate an interesting state of affairs. This section shows the wear due almost entirely to waggon traffic.

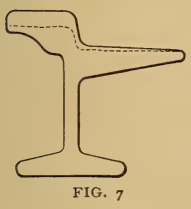


FIG. 7

Fig. 9 shows the rail used in Chicago at the present time in 7-inch construction with chairs or tie plates. The rail weighs 83 pounds and has a head 1 3-19 inch high, beveled as described.

Fig. 10 shows the rail used at the present time in 9-inch electric construction without chairs or tie plates. The rail weighs 90 pounds, and also has a head 1 3-16 inch high, beveled as described.

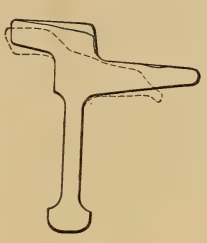


FIG. 8

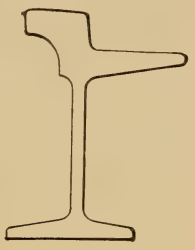


FIG. 9

The question concerning the composition of rails is one to be considered here also. The number of stops made by cars on electric railways are enormous, as compared with those on steam roads, and as a result of the short distance in which electric cars are brought to a stop, the wheels slide, sometimes spin, and this, together with the sand and dirt on the track, is a cause of great wear on both wheels and rails. This wear, together with that due to other causes, might be greatly reduced by proper composition of metal.

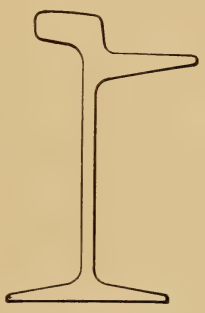


FIG. 10

It would seem that the harder a rail becomes through its composition and process of rolling, the longer it would wear. There are two schools,—those who advocate a low hardened and ductile material as having the greatest wearing resistance, and those who advocate the greatest possible hardness, regardless of brittleness. Some rails laid in recent years, after being in service but a short time, have shown abnormal wear in the way of small depres-

sions, about three inches apart, the full length of the rail, the surface having the appearance of being wavy, which would

POURING A CAST-WELD JOINT

indicate either faulty machinery in the mills, or improper mixture. Defects of this nature have been noticed in London, in Chicago, and in New York City. While no bad results have yet been experienced, and the defects are perceptible only to the keen eye of the practical street railway man, the matter is of sufficient importance to command attention.

The old adage, that the weakest point in a rope proves its maximum strength and durability, holds equally good in track construction; and the rail joint, inasmuch as it demands the greatest care and requires the largest expenditure for maintenance, proves to be the weakest point in tramway building. When we stop to consider the relation existing between a joint and other branches of the service, we find there is not one maintenance or operating account that is not affected detrimentally by poor joints.

The influence of the joints can, perhaps, be more thoroughly appreciated by weighing the different phases of the following quotations from a recent discussion on steel rails:—"The stiffer the rail, the less the creeping, due to the wave which runs ahead of the wheel, the less the wear of the ties due to this motion, the less destruction to track and running gear due to the pounding of the wheels, and the easier the hauling of trains."

The cast-welded joint, and the increase in the length of rails from 30 to 60 feet, have, it seems, solved the problem of a smooth and durable track; they give us the long-cherished ideal track without "bumps" and minimise the cost of maintenance.

The cast-welded joint was first introduced in 1894, and out of the total of about thirty-five thousand joints welded for one American street railway company, less than one-half of one per cent. have broken or shown any sign of defects, notwithstanding the extreme changes in temperature to which they were subjected. A new joint was in every case made in place of the broken

FIG. 11

one, as soon as the defect was noticed. To increase the mechanical efficiency of this joint, it has been found good practice to apply a 1¼-inch round iron plug, 2½ inches long, through the web of each rail before pouring the joint

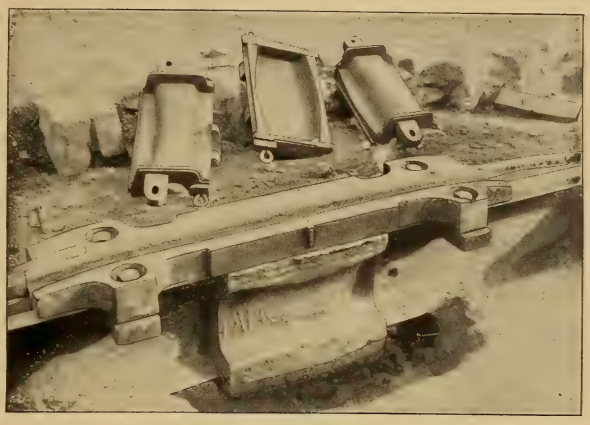
A PORTABLE CUPOLA USED IN MAKING CAST-WELD RAIL JOINTS

metal. This plug fits tightly in the rail, and by extending on either side, gives the result of a more rigid union between rail and joint, due to the condition produced by the molten metal adhering to the plug on all sides. Fig. 11 exhibits rail ends ready to receive the joint metal with plugs in place.

With iron plugs thus inserted, the joint, in comparative tests, has proven far stronger than the rail itself, and such breakages as have occurred in the joint were due either to a flaw in the poured metal, too much scrap iron being used in its composition, or the metal being poured too cold. In a few instances 90-pound, 7-inch rails have been pulled apart or broken by contraction 5 to 6 feet from a joint, which sufficiently demonstrates the tensile strength of the joint when perfect amalgamation takes place.

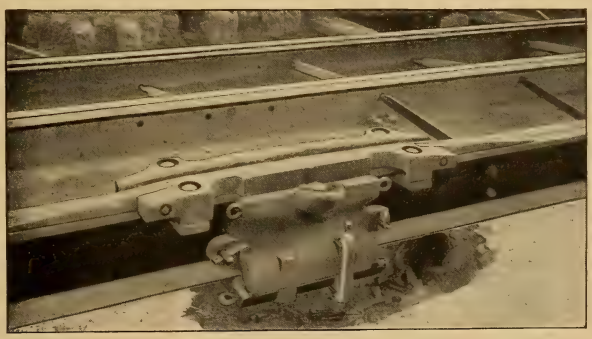
It has been found in some cases, where this joint was used at crossings with other tracks, that the tracks were apt to be pulled out of alignment through the changes of temperature. To overcome this, the joint nearest the crossing should be anchored in a substantial manner.

The method of making the joint is as follows:—The rails at the joint are scraped and brightened, a cast iron mould is placed around the rail ends, making a tight fit; into this the molten metal,—25 per cent. scrap, 25 per cent. soft, and 50 per cent. hard silicon pig,—is poured. The metal in contact with the mould begins to cool and form a crust while the interior remains in a molten state. This crust continues to cool and at the same time contracts, forcing the molten metal towards the centre of the joint. The top or bearing surface of the rail is afterwards filed off perfectly smooth, so that it is difficult to detect a joint by riding over it. Upon breaking a joint that has been well cast, three spots will usually be found where amalgamation has taken place between the rail and joint metal, one on either side of the web and the other on the bottom. These spots are from 1½ inches to 2 inches in diameter.



BRIDGE FOR COVERING JOINT

A great deal has been said and written regarding the probable conductivity of the cast joint, and there appears to be no doubt left that the joint, in itself, is as good a conductor of electric current as the rail. The only barrier in the way of a cast-welded joint properly performing the service of a copper wire, lies in the degree of amalgamation that



JOINT READY FOR CASTING

takes place when the metal is poured into the mould. However, in event of perfect amalgamation of the two metals, it has been sufficiently proven that the expenditure to bond around the joint with copper is entirely unwarranted.

In order to obviate any defect that might occur in the conductivity of the joint by improper amalgamation, the oxide and scale which usually form on iron or steel are removed from the rail ends by emery paper cleaning. But this has been found, in some cases, insufficient to insure the desired results. The consequent necessity of more thoroughly preparing the rail to insure the highest degree of amalgamation has led to the use of a sand blast cleaning machine, which consists of two air-receiving cylinders, one being about 24 inches in diameter and 5 feet long, and the other 15 inches in diameter and 4 feet long, charged by an air compressor, which is driven by a 10 H. P. 500-volt motor, all conveniently mounted on a low four-wheeled truck drawn by one horse.

Power is applied to the motor by hooking a pole over the trolley wire and grounding the motor to the street rail. No. 1 air reservoir, which supplies No. 2 air reservoir, receives the air from the compressor at about 15 pounds pressure. No. 2 air reservoir, standing perpendicularly, has, at its top, the sand hopper and sieve, two sets of valves, and the proper arrangement for forcing the sand out through a 2-inch heavy hose about 15 feet long, having at its end an ordinary 6-inch brass nozzle with a 3/8 to 1/2-inch opening. A man protected with a helmet, similar to a diver's helmet, supplied with air from No. 1 air reservoir, handles the hose and applies the sand blast to the rails, taking from two to four minutes to clean a 7-inch rail joint, depending on the amount of oxide on the rail.

Sharp lake gravel or torpedo sand of about the size that will pass through a 1-16 or 3-32-inch mesh is used, about 2½ to 3 cubic yards being used to clean 150 joints. All oxide and scales are cleaned from the rail perfectly, leaving the surface of the rail clean and bright.

Joints broken open which were cast on a rail cleaned by the sand blast process showed in every case that a flux had taken place between the rail and joint metal, to the extent that the joint, as made up, could be considered a perfect conductor up to the capacity of the rail.

But it must be remembered that a perfect conducting joint, cast in the manner described, will not be possible even though the rail is well cleaned, unless, first, a fairly good-sized body of metal is used in the joint which will increase the tendency of the joint metal to fuse with the rail; and second, unless great care be exercised in having the joint metal at a white heat, and taking no chances in pouring metal that is chilled to any extent. In order that the best results may be obtained, the rails should be warmed at least, if not heated, so as not to chill the joint metal as it first strikes the rail.

In conclusion, it may be said that no branch of industry has been more rapidly developed or perfected than the systems of transportation, and chiefly in American cities. When we stop to reflect, we appreciate the transformation that has taken place during the past decade in all details of tramway construction and operation. Instead of the uninviting and ill-appearing horse or mule cars of not many years ago, running over tracks nearly as rough as cobble-stone paving, we now have large, commodious, well-heated and ventilated cars, elaborately equipped, operating over what is practically a continuous rail, without even an occasional rough joint to remind us of the days gone by, when the track seemed to be all joints.

LIGHT ELECTRIC RAILWAYS

By Dr. Louis Bell

THE light railway occupies a place quite by itself in the economics of transportation. It forms, or should form, the capillary system of the industrial circulation, keeping the vital forces of society in action in the boundless acres that, lying outside the regions of most intense commercial activity, still form the greatest storehouse of national life.

Those whose life and interest is in cities are apt, in times of prosperity, at least, to look upon rural districts as a playground, or at best, as a sort of exaggerated kitchen-garden. Only in times of dire stress do they realise that when the farmer burns his corn for fuel an evil day is near at hand. As urban population grows denser, the need for more perfect channels of communication with the country and in the country grows stronger and more urgent.

It has been in recognition and furtherance of this necessity that, of late years, much encouragement has been given in Europe to the construction of light railways designed to meet the special conditions of rural traffic. In Belgium, in Prussia, and even in conservative Great Britain, vigorous effort has been made to stimulate the growth of these rural railways, and there seems to be a keen appreciation of their economic importance which is lacking in the United States. Americans are still far too apt to esteem a transportation system great in direct proportion to its bonded indebtedness.

The one salient characteristic of rural traffic is its uncomfortable tenuity. The total volume of business is, of course, enormous, but it is in so far scattered that in order to handle it with a reasonable assurance of profit railway construction must be relatively cheap, first, last, and always. In this connection it must not be forgotten that a light railway in Europe means something very different from that which should properly be so designated in the United States. The Continental roads, while generally of narrow gauge and very cheap compared with the usual Continental standard railway construction, still seldom cost less than $10,000 (£2000) to $15,000 (£3000) per mile, built and equipped. In Great Britain the Light Railways Act has not yet been long enough in force to bring the genuine rural railway into prominence, and most of the lines authorised under it have been of the common 4 ft., 8½ in. gauge, and certainly not less costly than ordinary American lines, built with an eye to economy.

Wherever there is, or is likely to be, enough traffic to support an ordinary railway, one is quite likely to be built. But to support a railway, costing, equipped, $15,000 to $20,000 (£3000 to £4000) per mile, a considerable density of traffic is necessary, and while in opening to settlement a new country the certainty of growth may justify considerable expenditure, in a region already well populated and beginning to segregate into urban communities it is not safe to count much on increase in purely rural traffic. When rural population is condensing into cities one must take rural business as it is.

Hence, when, twenty years ago, narrow gauge railways came to be in vogue,

they filled no particular want. There was a vast territory yet to be developed, and each road aspired to become part of a great through system with rapidly growing cities following in its wake. Consequently a cheap narrow gauge line was seldom necessary. Besides, as one of the railway building magnates of the period frankly put it:—"When I can build a road for fifteen thousand dollars a mile and place bonds at par for forty thousand, why should I stop building?"

At present, however, there is both a legitimate field and a strong reason for the light railway. Between large centres the haulage charges have come to be fairly low, but elsewhere they are high, and, high or low, there is still the waste incurred by long distance cartage to the scattered railway stations. This economic disadvantage is one of the many causes that has produced the serious and menacing depletion of the rural population during the last two decades. Evil betides a land of dwindling and deserted villages. As well can a tree flourish without its leaves.

It is the proper function of light railways to bring to rural districts something of the facility of intercourse that ordinarily belongs to larger towns, and so to cheapen transportation as to lessen the industrial handicap that now is slowly starving out the rural population. To this end these railways must be of such cheap construction as to pay on a very limited traffic, and must aim chiefly at competition with the horse and not with existing railroads, to which they will often serve as feeders. Ultimately they should ramify until they form a great industrial network, designed for cheap transportation, and still leaving for the trunk lines the fast and heavy traffic.

The rapid growth of suburban electric railways has already done an admirable work, more far-reaching than we can at present fully appreciate; but the remedy is still not sufficiently radical. Electric roads of standard gauge and the usual construction cost, even with rigid economy, from $10,000 to $12 000 (£2000 to £2400) per mile, which is not justified by rural conditions save in rare instances. That some of them pay even under these strenuous circumstances speaks volumes for the possibilities of roads really adapted for their conditions.

The service being light, track and rolling stock should be correspondingly light, thus lessening both the first cost and the dead weight to be hauled. To save fixed charges, due to cuts and grading, the light railway must be flexible, capable of taking sharp curves and sometimes rather severe grades, for it must, if necessary, wander in search of business.

Recognition of these conditions has resulted in the construction, on the European Continent, of hundreds of miles of narrow gauge rural railways confining themselves to their legitimate work and operated at a fair profit. A gauge of one metre is rather the favourite, although 60 c.m. is not uncommon, and even narrower gauges have been occasionally employed. The rails run from 20 or 25 pounds per yard up, and the rolling stock is correspondingly light. One recent authority, in speaking of rails, gives us a rough-and-ready rule that the rail should weigh about 6 pounds per yard for each ton per axle of the load.

Built on such lines, a light railroad can be taken profitably among farming villages and along country roads. The speed need not be great, and even with many stops the power required is not large, if the schedule time is only ten miles an hour or less. We can the better appreciate the economic significance of the system by a casual examination of its cost and operating expenses, as derived from such experience and knowledge as is at hand.

The cost of permanent way in railway construction is a variable of the most erratic character, depending, as it does, on the topography of the region. In open, level country the advantage of the light, narrow-gauge construction lies simply in the lessened cost of material, due to the actual dimensions, and the saving of labour due to the lessened weight to be handled. In rough coun-

try this advantage is immensely increased by the great saving in cuts and fills, in culverts, bridges, and viaducts, and in the saving that comes from improved location.

A narrow-gauge line carrying moderate loads at moderate speed can take curves and grades that would be quite out of the question for fast and heavy service, and, hence, can readily avoid, or surmount, obstacles that would be very serious in ordinary railway work. These are the same advantages that, in lessened degree, show in the ordinary practice of electric railways of standard gauge which do not aspire to high speed or the hauling of long and heavy trains.

With all this in view, and bearing in mind that the objective point of a light railway is to displace haulage of freight and passengers over rough country roads, we can form an approximate idea, at least, of the probable cost.

Right of way can, in nearly every case, be obtained free over the very roads of which the usefulness is to be thus supplemented. In case short cuts are desirable, right of way would very frequently be given by the land owners who would be directly benefited. This is often the experience with ordinary electric roads, and would *a fortiori* be true of narrow-gauge roads taking up much less room and aiding the abutters more directly.

There is at present a slight prejudice, partly natural and legitimate, and in part actively fomented by existing railways, against thus giving right of way to a private enterprise along the public domain. The roads, however, are for public benefit and convenience, and it is quite as legitimate to lend them to a purpose which will serve this end, as to retain them in their pristine inefficiency in order to aid other private enterprises in stifling competition.

It is, too, a decided advantage to the community to gain, by thus conceding certain public rights, such control of the enterprise as will ensure good service and prompt utilisation of franchises. There is often a most reprehensible tendency to secure franchises, not for the purpose of building lines so much as for speculation or to prevent building. The more closely the rural community identifies itself with proposed lines, the more likely it is to benefit by their operation.

Given the right of way, the construction of the road will involve an expenditure obviously dependent on the nature of the ground. At present prices the material of construction can be cheaply obtained. Assuming a gauge between 24 and 30 inches, European practice indicates the use of rails weighing about 25 pounds per yard. For a rough estimate these may be taken at $30 (£6) per ton, making a total cost of about $1200 (£240) per mile of track for the rails.

Ties, spikes, and miscellaneous supplies we may reckon at about $500 (£100) per mile, if wooden ties are used, as would generally be the case. Special work for switches, sidings, extra rails and the like will probably add $300 (£60). Freights and haulage mean $200 (£40) or more additional.

In fairly easy country, grading and surfacing will amount to, say, $600 (£120) per mile, and laying and ballasting to, say, $500 (£100) per mile more. This brings the total to $3300 (£660) per mile, and adding, say, $200 (£40) per mile for engineering and miscellaneous expenses, we may fairly say that $3500 (£700) per mile will put down a good substantial narrow-gauge track under ordinary conditions. This, however, supposes no bridge or trestle work of any moment, and fairly level country roads alongside the track.

Bridge work can generally be avoided by utilising bridges already existing, save for small streams encountered in taking short cuts. Where such short spans are necessary, they can usually be of very simple construction, and often can be put in place for $5 to $10 (£1 to £2) per linear foot. With tact in arranging a route, expense for such work can ordinarily be kept low. Frequently a light railway can follow the public roads entirely, and fully utilise existing bridges at a slight expense for occasional strengthening.

As to motive power, all indications

point to the use of electricity. A motor car is a far more desirable neighbour than a steam locomotive under all circumstances, and much more convenient to operate. Moreover, it can secure the necessary adhesion with very moderate gross weight, and is vastly easier on the track than a locomotive of equivalent power. On the whole, too, the electric equipment is cheaper to install than light steam locomotives for the same service and somewhat cheaper to operate.

To get a fair idea of the total cost of a light electric road we may assume ten miles of track of the character just described. Such a line would probably require two trains in steady service. These trains would not require a large amount of power for the service contemplated. The trains would hardly exceed 10 or 12 tons in total weight, and would ordinarily be less than this. For such weight, and ordinary speed and grades, the power required would seldom be over 15 H. P. This means that a capacity of 40 to 50 kw. at the station would be ample for the two trains. To distribute this amount of power from a station near the middle of the road a single No. 0 trolley wire would be quite sufficient.

Using a cheap bracket construction or suspension from diagonal span wires, the overhead work can be very economically provided.

In fact, in ordinary country districts the track could be bonded and the trolley system erected for about $1000 (£200) per mile of road. Then comes the question of power station, car house and rolling stock. The power station should naturally be of the simplest description, containing a good high-speed engine, belted directly to the dynamo, a first-class tubular boiler, and the necessary station equipment. The cost of this machinery, installed in a combined power and car house, should not be more than $7500 (£1500).

Next in order comes the rolling stock. One could get along comfortably with two motor cars, a trailer and spare motor, a couple of freight cars and four freight skips, a couple of them fitted as coal cars. They should cost not over $6500 (£1300) all told. An additional $1000 (£200) should provide for waiting rooms and freight platforms at the termini. Going back now and counting the cost, it amounts to just $60,000 (£12,000), or $6000 (£1200) per mile of track ready for operation, and it is safe to say that, with careful economy, a very effective light electric railway can be constructed for this sum,—about one-half of the ordinary figure for a standard gauge electric road of this length. It is evident enough that such a road as this can pay fairly well where the ordinary construction would bring financial disaster.

As regards running expenses, the situation is equally favourable. The daily output would probably be about 300 horse-power-hours at the engine. This would demand nearly three-quarters of a ton of coal, or a corresponding quantity of wood, which is sometimes cheaper in country districts. In this connection it should be noted that one cord of average dry hardwood is equivalent to about half a ton of coal, and average soft wood to about three-tenths of a ton.

The annual fuel bill would, then, taking coal at $3 (12sh.) per ton, rise to about $800 (£160) per year. An additional $500 (£100) should cover supplies and ordinary repairs at station and on cars. The labour necessary would be regularly six men, with occasional other help. The line should normally run about 12 hours per day, or a little more, so that no extra shift of men would be required. The labour account would probably be about $4500 (£900) per year. Allowing $500 (£100) per year for miscellaneous expenses, the total yearly expense would amount, in round numbers, to $6500 (£1300), possibly a trifle less.

We can now judge of the gross receipts that must be taken in to make the line pay. To earn six per cent. on the investment, the receipts must be about $10,000 (£2000) per year. At $9000 (£1800) the line would earn only four per cent. If depreciation is to be properly taken care of, about three per cent.

should be set aside as a sinking fund, so that to keep up the property and earn six per cent. net for the stockholders, would require gross receipts of nearly $12,000 (£2400).

Fortunately, there is a wide difference between rural light railways and ordinary steam and electric lines in the matter of tariffs. The former are in competition only with ordinary haulage by horses, and can, consequently, get remunerative rates for both passenger and freight traffic, while still greatly cheapening transportation along the line.

A passenger charge, based on about 2 cents (1d.) per mile, with a minimum fare of 5 cents (2½d.), meets the conditions very well, and a freight charge of one cent (½d.) per cwt. per mile, with a similar minimum charge and a reduction on large weights or carloads, would often meet the conditions. Ordinarily the schedule would consist of about 8 or 9 round trips per day, and to earn $9000 (£1800) per year the gross receipts must be about $3 (12sh.) per round trip. An average of half a dozen through passengers per single trip, or their equivalent, and a little freight, would yield this revenue, and two or three more passengers, with a very moderate amount of freight, would bring the receipts up to the point where the line would pay very creditably. Certainly there are plenty of rural districts where this amount of traffic could quite readily be secured.

There is another line of work, quite apart from the principal function of light railways, in which they can readily be made profitable. In many sections of the country the greater part, sometimes practically all, of the passenger traffic is concentrated into a time space of four or five months. Such conditions exist in the very numerous summer and winter resorts, which are often located far off the regular lines of travel.

In these places there is ample business during part of the year, and little or none the rest of the time. A railroad or tramway of any kind is, therefore, obliged to earn enough during a brief period to carry it through a long season of enforced idleness. For such conditions a light electric railway is admirably suited, for the investment is so moderate that the burden of idleness is greatly reduced. A road, for instance, such as has just been considered, could, with very ordinary traffic conditions during the summer months, clear a handsome profit on the investment, even if it was shut down, or run at a small loss, during eight months of the year. Under similar circumstances an ordinary road, demanding double the investment, would inevitably fail. Obviously, in this temporary service the less the investment, the greater the opportunity for profit, unless the earning capacity is greatly reduced.

In the case in hand the train service could be doubled by a comparatively small increase in the original investment, and the material advantage of a frequent service could thus be gained.

The objection generally urged against light railways is the inconvenience arising from a break in the gauge, compelling transshipment of all freight, since the light rolling stock will not interchange with the standard.

In point of fact, this objection arises from the false assumption that light railways are to be regarded as an integral part of the general railroad system. There is no more reason to complain of having to shift freight from a light railway than there is to bemoan the inability of a farm wagon to run on a railroad track, or to denounce a macadamised road because it will not accommodate a Pullman sleeping car.

The moment a light railway takes the standard gauge and tries to exchange cars with ordinary lines, it rapidly demolishes its track and private rolling stock and greatly increases its running expenses. To accommodate heavy cars and otherwise do general railway service, it must adopt ordinary methods of construction and thereby give up those characteristics which constitute its economic importance. Hence if light railways, as such, are to fulfill their purpose, they must abandon the attempt to do heavy railway service and confine themselves to their own sphere.

The need of cheap construction and

low operating expense practically enforces the use of narrow-gauge roads, or their equivalent, and by proper mechanical arrangements the labour of shifting freight at junctions with ordinary lines may be very much reduced.

There is something to be said for the bicycle and saddle-back plans of construction for light railways. Although at present in nothing more than experimental service, these single-rail roads have fully as great flexibility as the ordinary narrow-gauges, and can generally be built somewhat more cheaply. Of the various forms proposed, the bicycle road is, on the whole, the simplest and the most economical in construction. It is readily adapted to a cheap and strong trestle construction in crossing rough country or avoiding fills, while lending itself more readily to surface work than the saddle-back roads.

That such a single-rail road can be built and equipped rather more cheaply than a common narrow-gauge road seems reasonably certain. In ordinary country the saving may be roughly estimated at from $500 to $1000 (£100 to £200) per mile; in difficult country it would often be much more. The advantages of such methods in heavier railway work need not be here discussed, although they deserve respectful investigation, but for pure light railway service they are undeniably great.

Whatever form of construction is taken for a light railway system, the economic considerations are about as already set forth. From the standpoint of the electrical engineer, the equipment of such a system presents no difficulties. Most roads of this class are likely to be of moderate length,—say, five to fifteen miles,—and the distribution of current in the small quantities involved is a very simple matter indeed. A trolley wire of moderate size, or, in the monorail systems, one of the guide rails, will serve both as distributing and working conductor, and ordinary voltage, say, 600, is quite adequate to give a reasonably economical distribution.

It is only when light railways, at first usually merely feeders of an existing railway, grow into a connected system, or stretch out to furnish transportation in some extensive rural district, that any difficulties of distribution are likely to be encountered. In such cases these difficulties must be met, as in the case of ordinary street railways, by some system of power transmission. Not infrequently, in rural districts, a water power may be advantageously utilised, and in the case of a considerable group of light railways, a common power station, with transmissions to the various lines, would very often pay.

When the alternating motor is thoroughly developed for electric railway service, all these distribution problems will be much simplified; but even at the present time, so far as light railways are concerned, distribution is very plain sailing.

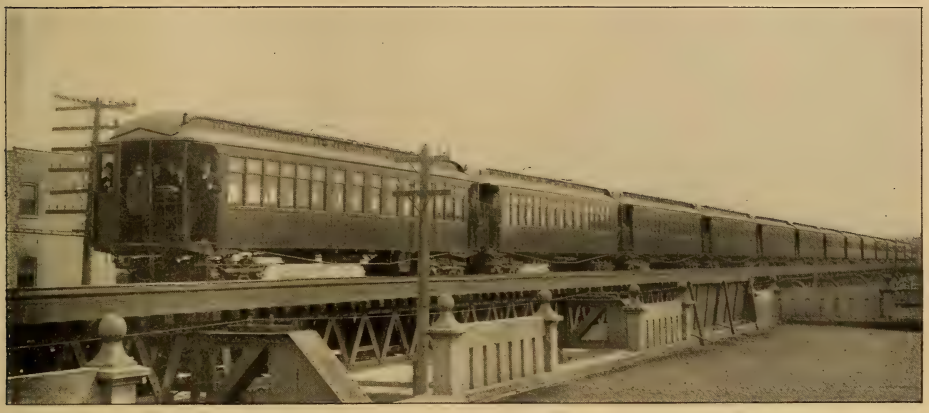
As to general engineering methods, each case must be treated on its merits, for each case presents its own traffic conditions, which must be met by such provisions as best suit them. The fundamental purpose of light railways is to care for the local and rural traffic that is now carried on by the most primitive means, furnishing transportation between the farm, the village, and the railroad, and of this purpose one must never lose sight.

Such roads can be made to pay on their merits in a very large number of cases. Their greater and ultimate function should be to furnish not only easy access to railroads, but direct communication between village and village, linking rural communities with one another and with neighbouring cities in industries and in interests.

Most of the influences which tend to produce overcrowded cities at the cost of a desolated country are directly produced by the lack of proper facilities for rural transportation, for industries and population naturally gravitate to railroad centres and to seaports. Perhaps we are destined never to return to a more uniformly distributed prosperity, but if there may be any hope of so fortunate a change, the first step toward its realisation is escape from rural isolation by such means as have been here suggested.

THE MULTIPLE UNIT SYSTEM FOR ELECTRIC RAILWAYS

By Frank J. Sprague



A THIRTEEN-CAR MULTIPLE UNIT SYSTEM TRAIN ON THE SOUTH SIDE ELEVATED RAILWAY AT CHICAGO

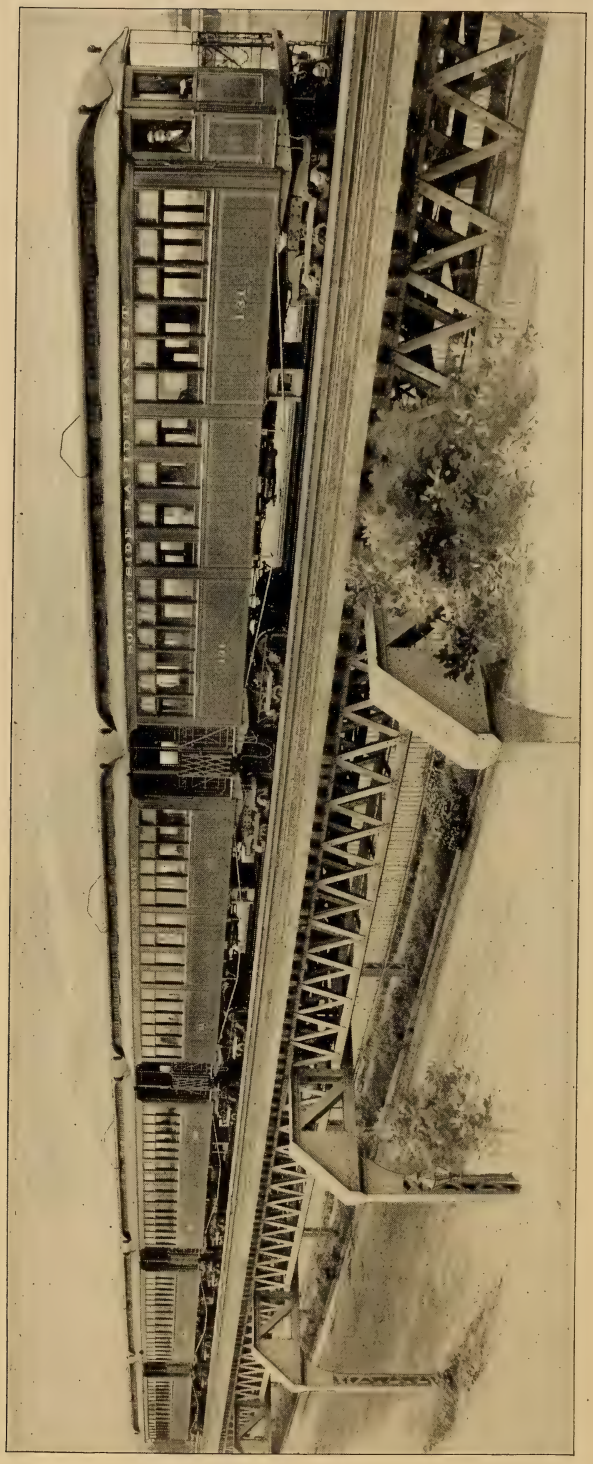
A NEW development and a radical departure in railway practice,—possible only to electric application,—has marked the past two years of electrical progress, and is destined to create a revolution in railway operation. It is based primarily on the fact that rapid transit by means of wheeled vehicles ultimately reduces itself to a question of the proportion of weight upon the driving wheels. All other matters entering into the question for any given case and set of conditions, such as schedule speed, traffic capacity, extent of equipment, total investment, operating cost, safety, and even reliability of service, are incidental to, and directly or indirectly dependent upon, the adhesion of the driving wheels of the vehicles to the track.

The fastest possible car movement between stations can always, under equal conditions of equipment, load, grade and power supply, be made by the vehicle which has the greatest percentage of weight on the drivers. Therefore definite theoretical and practical limits exist for railroad schedule speeds under any given conditions, and the highest schedules in any case can be made only by a train system which preserves under all circumstances the specific characteristics of a motor vehicle with 100 per cent. weight on the drivers.

In the present stage of development of rapid transit systems for urban, suburban and inter-urban service, where stations are close together, traffic much congested in the morning and evening, and yard and terminal facilities limited and costly, high schedule speeds are absolutely essential.

There are three distinct generic methods of railroad operation:—the single car operating independently; the locomotive pulling trail cars; the multiple unit system, or aggregation of transportation units, each fully equipped, into trains, and provided with a secondary control.

The first received its great impulse at



A FIVE-CAR TRAIN ON THE SOUTH SIDE ELEVATED RAILWAY AT CHICAGO

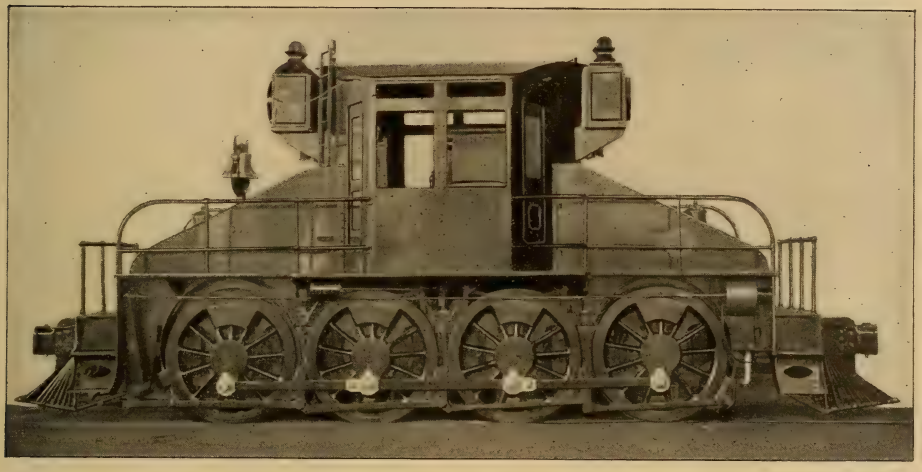
Richmond, Va., U. S. A., in 1887-8. Its history and characteristics, illustrated by tens of thousands of electric trolley cars in daily operation, need no detailed description. Each car is a motor unit, with large effective driver weight, from 80 per cent. to 100 per cent., and is equipped with hand control, but incapable of aggregation into trains with localised control. This system broadly includes all modern street railways.

The second, or locomotive system, follows steam precedents, and is subject to the limitations of steam engineering, in which there is concentrated in a single unit the weight and power necessary to handle a train under given conditions. This locomotive idea has taken two forms, one of which copies one or the other of the many types of steam locomotives, with such modifications as are permissible with electric motors, but which, despite the remarkable general progress of electric railways, still finds but few applications in actual practice. Notable among these are the Baltimore & Ohio tunnel locomotives at Baltimore, Md., U. S. A., and the equipment for the Central London Underground Railway. Among the earliest, if not the first, of the large electric locomotives, is one of 1000 H. P. capacity, built by

the writer and his associates for the North American Company about seven years ago.

Another form of the locomotive may be described as the locomotive-car, which consists of a car body of the usual form, arranged to carry passengers, with one or both trucks equipped with motors,—hence with the weight distributed over a considerable distance, and with, as in the other case, hand control provided at either end of the car in a suitable cab.

Such a one was experimented with by the writer on the elevated railways in



A 60-TON ELECTRIC LOCOMOTIVE BUILT FOR THE NORTH AMERICAN COMPANY BY MESSRS. SPRAGUE, DUNCAN & HUTCHINSON, NEW YORK

New York City in 1886-7, where the first modern railway motor was used, and a special car was built about the same time which was to have had an equipment of two double armature 75 H. P. motors on each truck. This was before the days of the historic Richmond road, and, therefore, before any of the modern advance in electric railroading. This type of locomotive-car was used on the Intramural Railway at Chicago during the World's Fair in 1893, and is now in operation on the Metropolitan and Lake Street Elevated Railways at Chicago.

A modification of this locomotive-car plan which has been more recently proposed consists in putting a locomotive-car at each end of the train, passing the main circuits through all the cars, and providing duplicate hand controls at each end of each locomotive-car for the eight motors constituting their equipment. The system is untried, presents innumerable difficulties, has most of the defects of the locomotive system, but constitutes an acknowledgment of the necessity of greater weight on drivers and greater power for meeting the requirements of modern transportation.

All these methods,—the single car, the locomotive, and the locomotive-car, as well as the doubling-up of locomotive-cars,—fall short of meeting the requirements of a flexible railway system to be operated on a high schedule. The single, high-powered car, using all of its weight on the drivers, and with effective control, needs no commentary so far as the ordinary application is concerned, but the methods proposed for the aggregation of cars, and the handling of trains through the medium of a locomotive or locomotive-car, or aggregation of hand-controlled locomotives occupying fixed relation, utterly ignore the possibilities of electric application, and the advantages manifest in every car operated on the street.

In some form or other this has been recognised for a number of years, and

it occurred to a number of engineers that for increased adhesion, and to provide more power with reduced local weight, motors could be distributed throughout the train, the mains carried through it, and the system governed by a main controller at the leading end.

One of the earliest of these proposals was made by the writer before the Society of Arts at Boston, in 1885, just prior to conducting experiments on the New York elevated railways, at which time he contemplated the use of motors

THE FIRST ELECTRIC LOCOMOTIVE CAR. BUILT BY SPRAGUE IN 1886 FOR EXPERIMENTAL WORK

on each car, or every other car, and a pilot locomotive, or locomotive-car, containing an adjustable controlling apparatus which could be made effective for handling two or more cars made up into a train. This project, however, never reached fruition, and, of course, falls short of the possibilities. Much more certainly seemed feasible. The excuse for the last-mentioned proposal was found in the evident engineering truth, that if greater power were applied to a train, and a high percentage of the weight on the drivers were utilised during acceleration, higher train schedules than any hitherto attempted would be possible.

Considering for a moment a single car as a unit, and putting all the available power which space permits into the motors connected to each of the axles, it is readily possible to provide a motor equipment of over 20 H. P. per ton moved, and to use 100 per cent. of the weight on the drivers. The possibilities of this unit, that is, using the weight of the car for traction, and all the power which can be put within the space permitted, are the limit, and absolutely the only limit, of the speed to be attained by an electric car. If, now, this unit be lengthened, that is, if the cars be aggregated into a train, and the same ratio of weight on the drivers and the same H. P. per ton be maintained, then, it matters not what the length of the unit, identically the same schedules can be made with the train as with the single car.

The most effective railway operation, however, required something more than schedule speed, and it seemed that, considered from a competitive standpoint, and with the idea of gathering every

ONE OF THE FORTY-SIX 23-TON BALDWIN COMPOUND LOCOMOTIVES ON THE SOUTH SIDE ROAD, DISPLACED BY THE SPRAGUE MULTIPLE UNIT SYSTEM

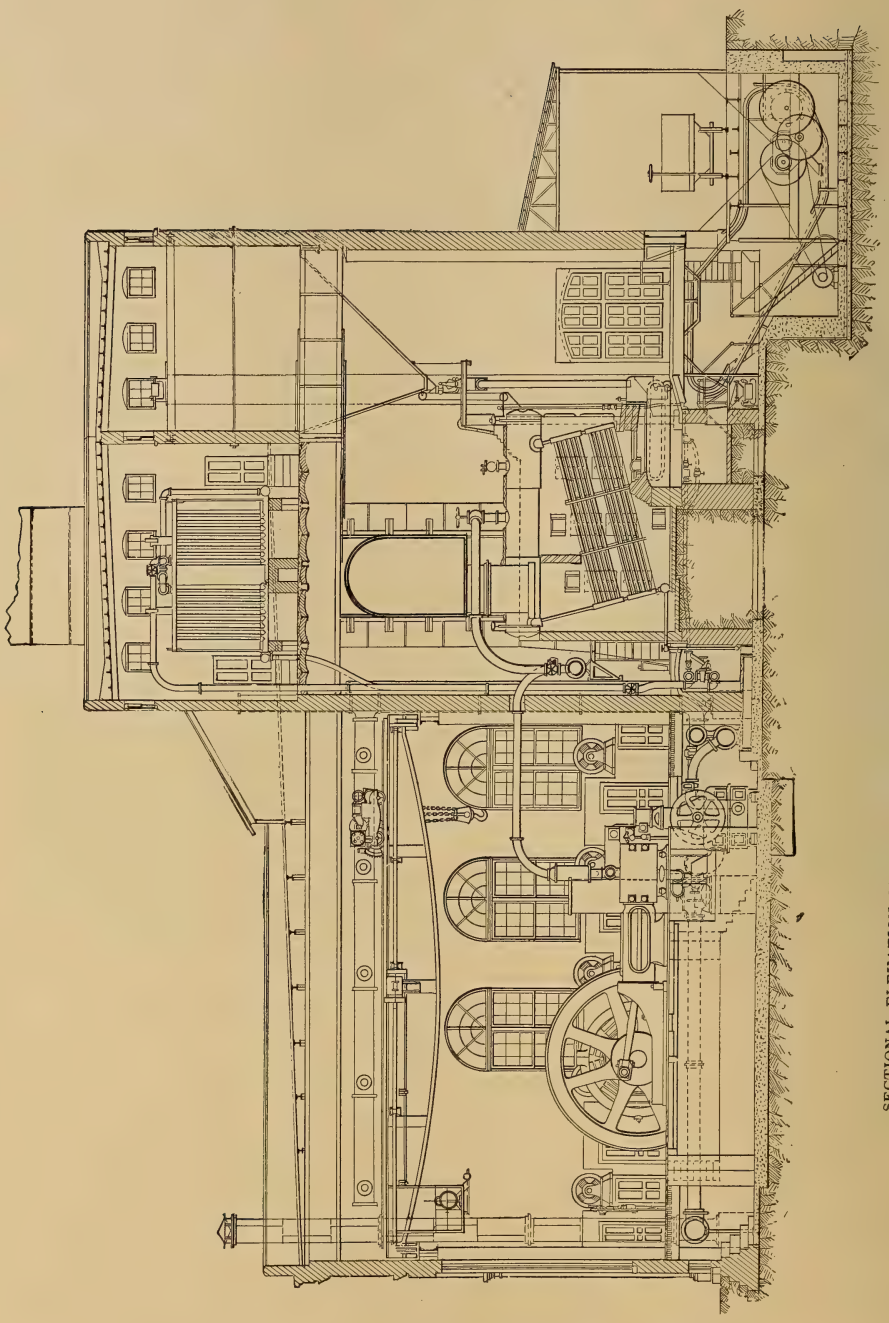
passenger possible, the proper method of operating a railroad should be something as follows:—

Starting at the time of least traffic, to operate the smallest allowable unit at intervals determined by the ratio of the increased cost of operation to the increase of passenger receipts obtained by shortening the interval; then, as traffic increases, to shorten up this time interval as far as is consistent with safety; and then to increase the size of train unit, while maintaining the same interval and high schedule, to take care of the greater traffic.

It may be said that smaller train units cost more to operate than larger ones. This is true, but against this is the simple fact that on the scale of wages paid on many railways, the difference in total cost between operating two 2-car trains and one 4-car train is one passenger per car for every 50 stations as spaced on the elevated railways in New York. In view of this fact, it can hardly be questioned that if shorter intervals are made possible, more passengers would be gathered than are represented by these differences, and trains would, if a practical multiple unit system were devised, be operated in any length from one car up.

In matters of transportation, the passenger's demands and the wishes of an operating manager are not always alike. The passenger requires for his convenience the most frequent time intervals, the shortest station waits, and the highest possible schedule speed. The railway manager is often tempted to concentrate loads, increase the time intervals, and let the passenger wait, but in so doing he may lose the passenger. With a locomotive-car system this is the inevitable result, because otherwise the entire motive equipment would be kept in continuous operation, at low economy and at great expense.

All these conclusions, together with many other advantages which would accrue, pointed unerringly to the necessity of the third generic system of railway equipment and operation,—that which the writer has termed the multiple unit system. It may be briefly described as a semi-automatic system of control which permits of the aggregation of two or more transportation units, each equipped with sufficient power only to best fulfill the requirements of that unit, with means at one or more points on the unit for operating it through a secondary control, and a train line for allowing two or more of such units, grouped together without regard to end



SECTIONAL ELEVATION OF THE POWER HOUSE OF THE SOUTH SIDE ELEVATED RAILWAY COMPANY

relation or sequence, to be simultaneously operated from any point in the aggregation.

For any given weight to be moved, whether it be one or two cars, there is a certain capacity of motor equipment with which it is best to operate it under any fixed conditions, and that is the motor equipment which should be put on that unit,—not something either larger or smaller; and then, when more capacity is required, to simply add another unit of like character. A unit may be a single car, or a pair of cars, and the number of motors used may be whatever desired, so that any desired ratio of weight on driver and any required power may be used. The logical equipment is two motors for each car, and, when so equipped, the importance of some of the practical results is emphasised.

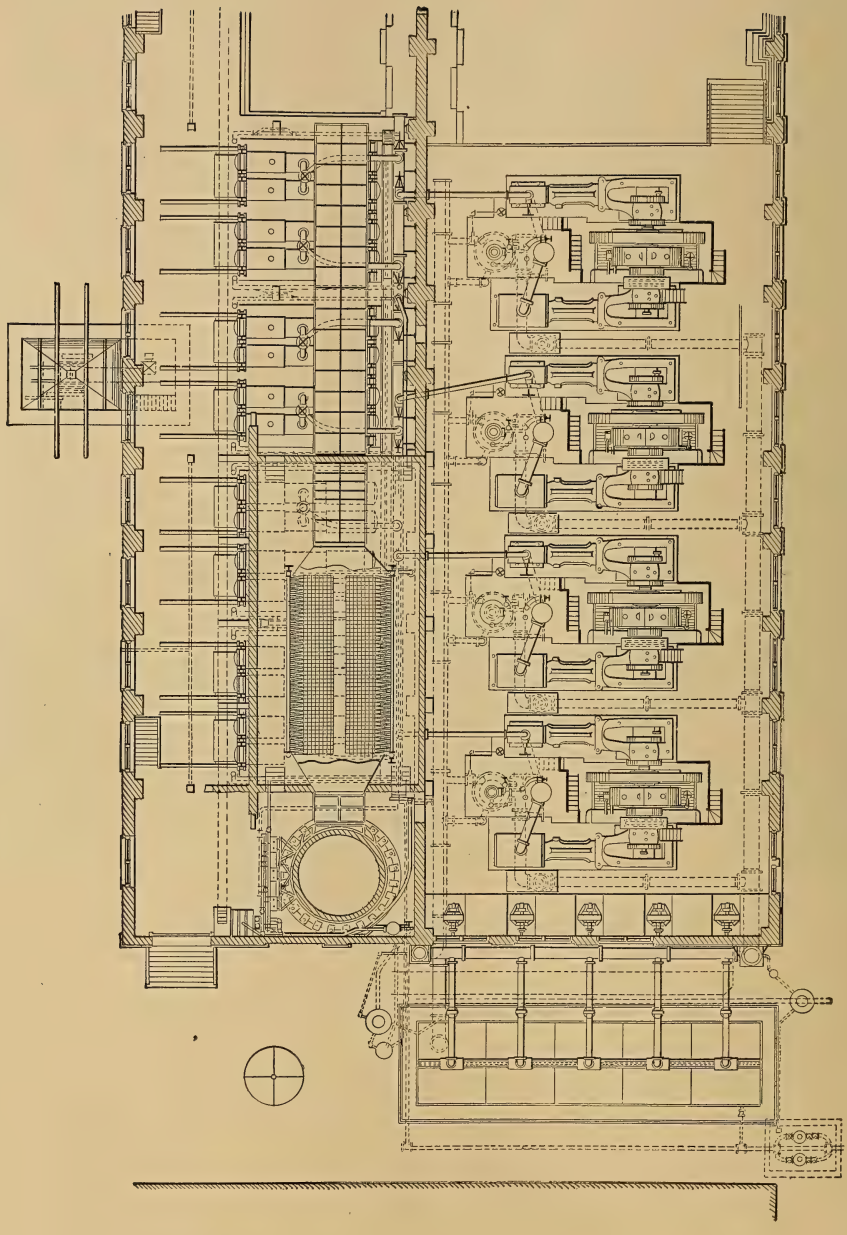
One of the advantages which such a general system possesses is similarity of equipments. This gives absolute flexibility of train operation, and insures like characteristics for trains, whatever the length and whatever the combination of cars. The motor equipment is directly proportional to the number of car units.

There is a practical fixed relation between the weight on the drivers and the total load, whatever the length of train, and it is a matter of indifference to the motorman whether he is operating one car or any aggregation of car units in a train, for its characteristics are always the same.

Each car being lighted, heated and braked independently, has independent movement in yards or car houses or on the tracks, wherever stored, and thus inspection, repairs and train combinations are facilitated. The head and tail switching, characteristic of locomotive practice, is entirely abolished. Trains in whole or in part can be reversed at any cross-over, thus reducing the dead mileage and intensifying the car movement to meet the conditions of passenger movement, and cars can be added to, or taken from, a train in a third of the time necessary with a locomotive system.

Where a system has main tracks with branches, car units for the different branches can be aggregated on the main line, and then split at the junction, thus preserving the time intervals on the branches, but doubling the distance in-

A MULTIPLE UNIT SYSTEM FOUR-CAR TRAIN BROKEN UP INTO ONE TWO-CAR TRAIN AND TWO SINGLE CARS



A PLAN OF THE POWER HOUSE OF THE SOUTH SIDE ELEVATED RAILWAY COMPANY

tervals on the crowded sections. The fullest use can be made of all sidings and tracks, wherever located, for storage, and, in a large measure, for inspection, which insures less dead mileage and useless returns, and effects concentration of car movement impossible where the cars must be stored in one place.

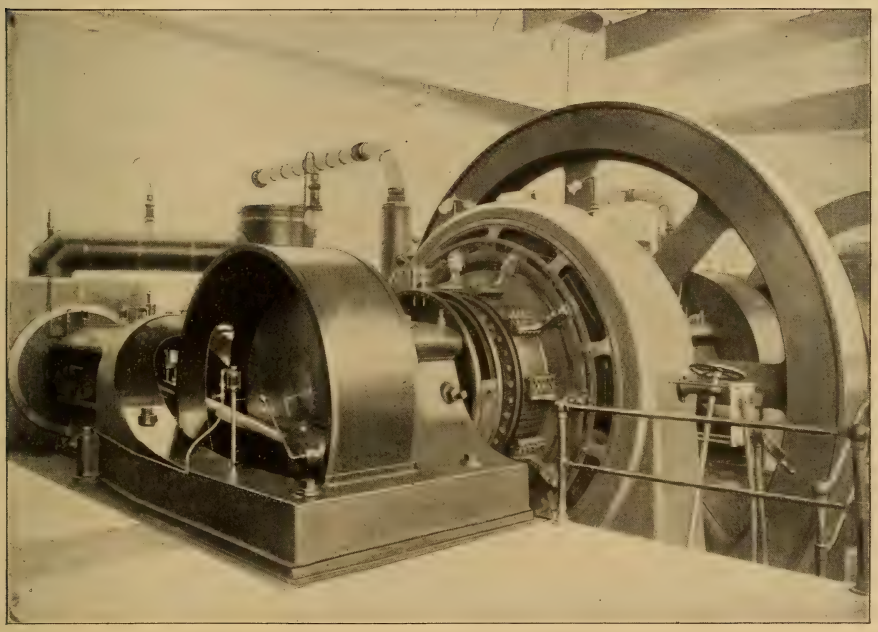
Any required rate of acceleration or schedule speed up to the maximum becomes possible, thus giving the highest schedule with any given maximum, and the lowest maximum with any given schedule. A partial equipment may be made by equipping alternate cars, and this schedule may be increased later by additions to the unequipped cars without changing the character of anything.

With this system the weight of cars, truck and motive equipment is necessarily less than with any locomotive or locomotive-car system, and this is of importance where elevated structures or bridges are used, especially where these are already possibly strained.

The hammering on the rail joints, with the resulting shock to the structure and to the moving train, will also be diminished because of the less weight per driver, and because the thrust strains for any given rate of acceleration are equalised and distributed over a considerable length of structure, becoming practically the reverse of the braking strains.

The safe time and distance interval between trains for a given schedule and for any given length of train and station stop is dependent upon the maximum speed and the rates of acceleration and braking, and the greater these latter are with any given schedule, that is, the lower the maximum speed and consequently the less the travel of the train after the brakes are applied, which distance varies, roughly, as the square of the speed at the time of applying the brakes, the shorter can be both the time and the distance interval between trains, and in these respects the multiple system affords another advantage.

If there were an infinite rate of acceleration and braking, then there would



ONE OF THE FOUR 800 K. W. WESTINGHOUSE GENERATORS IN THE POWER HOUSE OF THE SOUTH SIDE ELEVATED RAILWAY

practically be necessary, barring accidents, only that time limit between trains occupied by a train at and blanketing a station, and in any case a motorman will approach a station with more confidence and under closer headway when his maximum speeds are low and the braking distance which he travels short, and when he has confidence that the train ahead, when once started, will promptly accelerate and increase speed while that of his train is rapidly diminishing. It is apparent, of course, that the length of a train is limited only by the platform accommodation.

From the standpoint of better equipment, it is to be noted that there are fixed limitations of wheel base, track gauge, wheel seat, diameter of axles and distance between axle and bolster, and hence there are practical limitations to the outside dimensions of motors. The smaller the capacity of the machine put into that space, the greater the margin for increase of dimensions of the essential working parts, such as bearings, gears and commutators, and the greater the freedom for inspection. More space also is available for the application of any kind of brakes, electric or mechanical.

With any given maximum hourly mileage, the number of cars in service, or on relay, will vary inversely as the schedule. This advantage is further augmented by those already instanced, the concentration of car movements where most desired, and the storage of cars at the most convenient points, with consequent less dead mileage.

The operation of the multiple unit system is very simple. Every motor car, or pair, being a transportation unit, and every aggregation of such being, so far as the motorman is concerned, simply an extension in the length of the unit without in any manner changing its character, the operation becomes almost automatic. Like hand and like train movement exists, whatever the combination and wherever the motorman may be situated.

The making up of trains, so far as electrical features are concerned, is as simple as coupling up an air hose. No main currents are carried from car to car,—only small currents, through reversible jumpers,—and the electrical combinations are effected automatically, however the trains are made up, and whatever the end relation of the cars. Protected by the automatic features, a child can handle full-sized trains on regular service with less trouble, so far as the electrical apparatus is concerned, and with less instruction than is required for the simplest form of air brake.

The train line and the main motor circuits being absolutely independent, and provision being made on every car for cutting out a set of motors, or a controller, facility exists for an easy inspection wherever the cars are located. Almost all the working parts of the motors can be inspected through a trap door in the bottom of the car, and since the cars have independent movement and can be rapidly run through an inspection shed over a pit, a little practice enables an inspector to make the most rapid survey of trucks, brake rigging, motors and everything else which is under a car.

Transportation wages per car-mile, the largest element of cost, are reduced because of the simplicity of operation, and because of the increased schedules. With the same efficiency, less power per car-mile is expended, and, hence, less coal is burned, for any given high schedule with like conditions of traffic than with a lower rate of acceleration, because of the less amount thrown away in braking. The increase of power required because of low acceleration over high is anywhere from 25 per cent. to 50 per cent. When it is realised that a system like the New York elevated railway would use only one-sixth of the power actually used now if it made no stops, the importance of this fact may be seen. Even this saving, however, is less important than other advantages.

The highest safety is essential. In the case of failure of brakes or on slippery rails, the machines throughout the entire train can be safely reversed. The current input to the machines is automatically limited on each one to its safe

capacity. In case an accident should happen to an operator, and he should let go of his controlling handle, the entire power would be instantly cut off from the train, and in case the controlling apparatus on the leading car should become disabled, the train could be operated from either end of any other car.

In fogs and on slippery rails a fixed schedule can be maintained more safely because of the lower maximum speed, the less distance travelled in braking, the greater confidence in approaching a station and the promptness of the leading train in getting away. On account of the reserve capacity of the machines it is possible to make up time, and to clear a road, which is a matter of the gravest importance on a congested system.

The multiple unit system means lowest first cost as well as lowest cost of operation. This is contrary to first impression, but the explanation is simple in that the cost of the delivery of electrical energy to the car shoes per unit of constant use is 8 to 10 times the cost per unit of maximum capacity of car equipments, and by using the higher rate of acceleration rather than the lower for any given high schedule, the aggregate cost of the total equipment from power house to car equipments for any given hourly mileage is less, because, notwithstanding the increased cost of car equipment, the difference of economy effects a saving in that portion of the electrical equipment, that is, generation and distribution, which costs so many times more per unit equipment than the units of car equipment, that the latter increase is more than made up by the saving in the former.

Such are the practical advantages to be derived from a multiple unit equipment. But to be effective, the details of the system had to be developed, at great expense and with much experience, to a state of absolute reliability. It may now be stated, however, that the essentials of the multiple unit system are not complicated, despite the remarkable variety of functions which they have. They may be stated briefly to be as follows:—

1. The master controllers on the platform at each end of a transportation unit. They are of the simplest and most reliable character.

2. The master controller and train line cables, which become parts of the permanent wiring of a car, and are just as reliable and as simple as those for the lighting system. These secondary controlling cables are absolutely independent of the main motor circuits, and carry very small currents.

3. The jumpers, which are removable sections of the train line, connecting the parts of the latter, which are permanent to each car, just as air hose couplings connect up a brake line.

4. The main master controller, which is composed of the following parts:— Certain relays and a throttle, developed in electric elevator service; pilot motor with automatic limits, something like that used in elevator controls, but of more robust make; a rheostat cylinder, with or without motor grouping switches, the parts similar to those of hand control; and a reverser with like parts, but independently operated.

The braking system, whether using automatic air or electric brakes, is something like the multiple unit electric system. There is a train line, with means at each end of each transportation unit for simultaneously applying the brakes. When air is used, there is a train and equalising line, a compressor with an automatic governor, illuminated gauges, and a simple form of engineer's valve at the ends of each car.

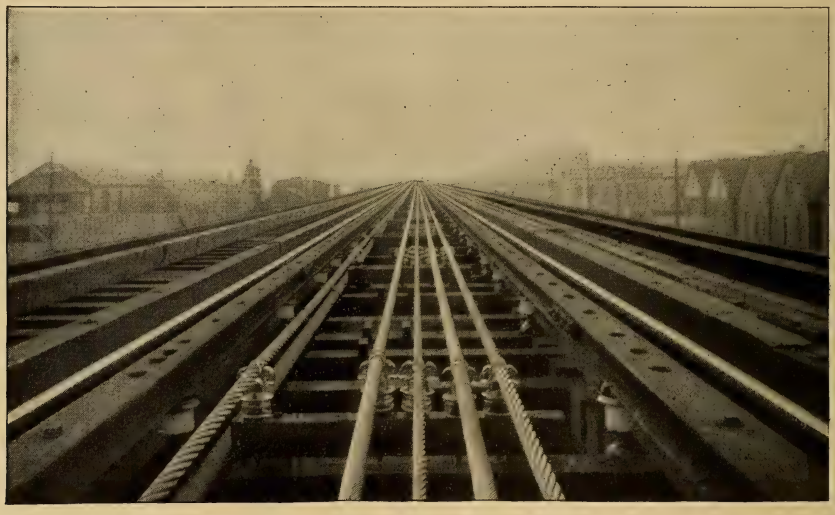
As with many other innovations, the opportunity to put a system which promised so much into operation was a long time coming. Many attempts had been made, with offers to conduct experiments on a wholesale scale at the writer's own expense, but with no satisfactory response, until he was very suddenly called in consultation on the South Side Elevated Railway at Chicago, and it is on this road that the multiple unit system in its present form has been reduced to practical operation, and on a scale of railroad development

and under conditions never before equalled in electric railroading except at Richmond, Va., the pioneer modern trolley railroad.

The South Side Railway had passed into the hands of a receiver, had been reorganised, and in the spring of 1897 had, under its new president, Mr. Leslie Carter, and a progressive board of directors, decided to adopt electricity, with Messrs. Sargent & Lundy, of Chicago, as engineers.

The original plan submitted by the various manufacturing companies proposed the usual locomotive car with either two or four motor equipments, but many difficulties presented themselves in providing for the necessary power and weight to get the increased schedule speed demanded, as well as to meet other requirements. The writer at once saw the opportunity for a radical departure, and the opportunity to commercially put in operation a multiple unit system. The advantages of higher schedules, reduced weights, variable train lengths, more frequent trains, distributed motive equipment and increased economy being presented, found ready appreciation, with the result that definite proposals promptly resulted in a contract.

Realising the gravity of the proposed departure in practice, the contract requirements were made of the most rigid character, and the conditions under which the equipment was to be installed were most onerous. The existing road is a double-track structure of the usual elevated type, extending from Congress Street to Stony Island Avenue, a distance of about 8 miles. Plans were already made to connect it with the new "Loop" in the heart of Chicago, on which the trains of the Metropolitan and Lake Street roads were already operating, and which was to receive also the trains of the projected Northwestern Elevated, with the prospect of grave congestion and the absolute necessity of freedom from serious blockades, which would stall the entire elevated systems of the city.



MAIN FEEDERS ON THE SOUTH SIDE ELEVATED RAILWAY

The road is paralleled by cable and electric street systems, by the Chicago and Rock Island road, and by the steam suburban service of the Illinois Central Railway.

The existing equipment consisted of forty-six 28-ton Baldwin compound locomotives, and 180 standard 43-foot, 15-ton cars equipped with Pintsch gas, steam heat and automatic air brakes.

The schedule speed on the main lines

was often 14 to 14½ miles an hour; trains were operated at intervals of from one and one-half minutes to half an hour, and in lengths of from two or five cars. The service, including the Loop, would, in cold weather, require from 145 to 150 cars, and 10 or 15 cars would ordinarily be under repairs.

It was necessary to take this equipment in its condition then, remove 10 or 15 cars at a time from the structure, partially equip them, return them to the road to allow them to be retained in steam service, again withdraw them, complete the equipment, and put them into electrical operation when the power house was ready, jointly with steam trains, without crippling the service.

The first contracts required the supplying and installation on 120 cars of lights, heaters, motors and trucks, as well as the supplying and developing *de novo* of an entirely new system of control, involving not only the actual construction of the controlling mechanisms, but the train system connected with it, such as couplers, jumpers, automatics, etc., the installation of a braking system, and the providing of both ends of the cars with vestibules or cabs.

The following were among the conditions of operation:—The simultaneous control of two or more independently equipped motor cars, to start, accelerate, operate at any speed up to their maximum, slow down, and apply automatic brakes, all with practically uniform effect in each and every motor car.

The automatic reversal and braking of the machines and cars in case of failure of current, parting of train, or running on to dead section.

With a normal potential of 500 volts, a single motor car or any number connected together in a train were to be able to maintain a schedule speed between existing termini of fifteen miles per hour, with average stops not exceeding ten seconds, for existing station distribution, and to be able to ascend a 2 per cent. grade at more than schedule speed.

The system of control was to be such that any number of cars so equipped could be coupled together indiscrimi-

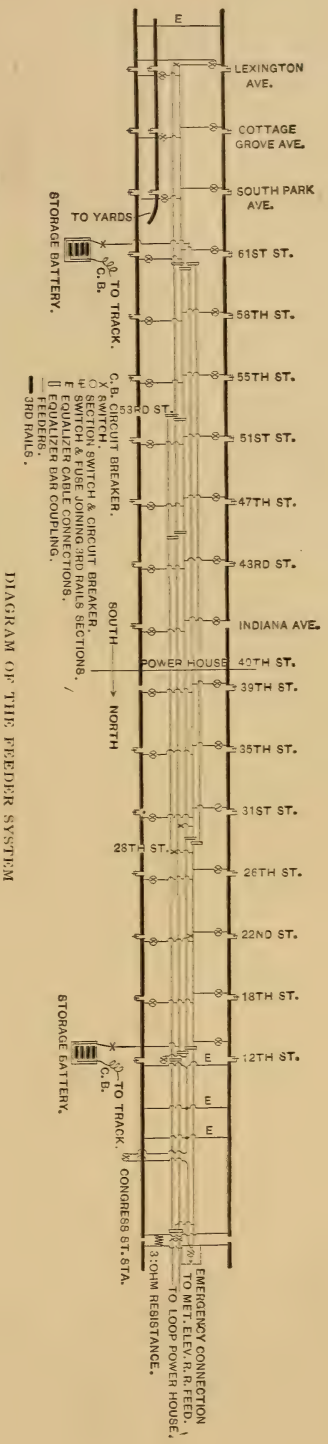


DIAGRAM OF THE FEEDER SYSTEM

THE FIRST MULTIPLE UNIT SYSTEM CAR ON THE CHICAGO SOUTH SIDE ROAD

nately without regard to their sequence, and when so coupled, by identically the same movement were to be controlled from any selected point at either end of any car, and the rate of acceleration, traction co-efficients, speed and braking conditions which characterise a single car were to be duplicated in a train unit, no matter what the number of cars.

The automatic braking devices and electrically operated power brakes were to furnish a perfect substitute for the air brake in use, in efficiency, reliability, and automatic action.

The contractor was to begin work on the equipment on 120 cars immediately upon signing of the contract, and to have six cars completely equipped, ready for operation and test, on, or before, July 15, 1897, on a standard track not less than one mile in length, to be supplied by him at his own expense; the test and the manner of its making, as well as its extent, to be prescribed by the officers and engineers of the road, and to be to their entire satisfaction. Should such test be unsatisfactory to any of these officials, or not concluded by the date set, then the right remained with the railway company to cancel the contract.

Should the test prove satisfactory, the cars were to be delivered wherever required for further tests, the remaining 114 equipments to be completed by specified dates, and as soon as the South Side power house and road were ready for electric operation, another test was to be made of twenty or more equipments under the actual service conditions of the road, which test was to extend over a period of at least ten days, and be made in such manner as required by, and to the satisfaction of, the president and engineers of the company.

In the event of these equipments proving unsatisfactory to any one of them, the company still had the right to cancel the contract, and to require a waiver of all claims against it. No acceptance of any part of the equipment could be required by the contractor until after these specified tests. In addition, a $100,000 penal bond for the carrying out of the contract had to

be filed. All these conditions were accepted.

On July 16, 1897, two cars were put into operation on a private track at Schenectady, N. Y., in the yards of the General Electric Company, which company, as well as a number of other subcontractors, accepted conditional orders from the writer for the various portions of the equipment which they could supply.

On July 26 a train of six cars, operated by the writer's ten-year-old son, was put into operation, and tests of the equipment in the presence of the officers and engineers of the South Side road were continued for several days.

On November 17 a train of five cars was put into operation on the loop and over the track of the Metropolitan Elevated Railway at Chicago, and continued for a number of weeks, operatng sufficiently satisfactorily to warrant the completion of the contract which was then in active prosecution.

The first car was run on the South Side road on April 15, 1898; on April 20, twenty cars were put into initial operation, and by July 27, 1898, locomotives had been entirely abandoned. Subsequently thirty "train line" cars for insertion in trains during periods of heaviest operation, or on special occasions, were added, and since then thirty more cars have been fully equipped.

The power house for the South Side road was built after plans by Messrs. Sargent & Lundy, and embodies several features which successfully obviate the disadvantage of a site removed from water supply sufficient for condensation, but which was chosen because it was near the centre of distribution for the railway system. The building is of brick and iron, and the engine and boiler rooms are separated by a brick wall dividing the building longitudinally.

The boiler installation consists of four batteries of Babcock and Wilcox boilers, rated at 400 H. P. each, equipped with chain grate stokers, filled from overhead coal bunkers of 1000 tons capacity.

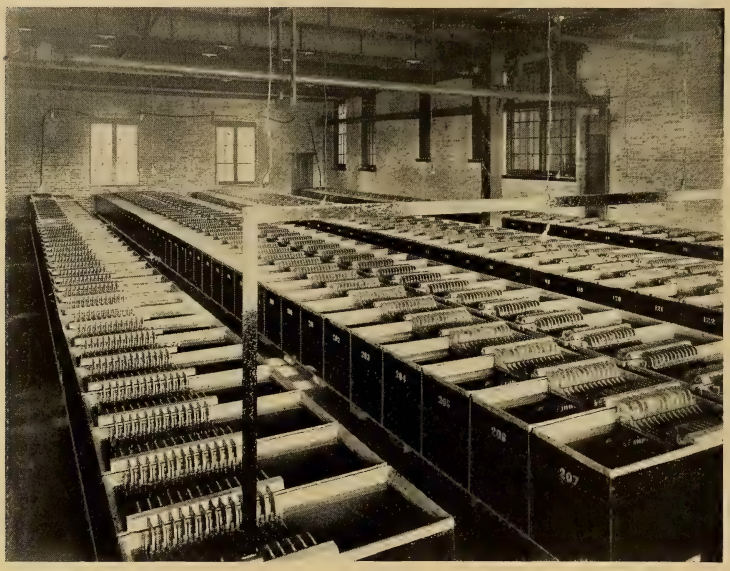
The chain grates are engine-driven,

READY TO PULL OUT. THE HEAD OF A TRAIN

and have speeds adjustable for ranges up to four inches per minute. Vertical shutters at the feed hoppers on the boilers regulate the depth of fire on the grates. The installation operates practically without smoke, except in starting fires. Ashes drop from the grates into sub-chambers, and are drawn off into an electrically driven coal and ash conveyor, which receives and dumps automatically when set as desired and started. The furnace gases, on leaving the boilers, pass through a Green fuel

economiser which effects 10 per cent. fuel saving daily.

The engine room is traversed longitudinally by a travelling electric crane of 30 tons capacity. It contains four cross compound condensing Allis-Corliss engines, each rated at 1200 H. P. at 80 revolutions per minute, with a maximum capacity of 2000 H. P. each. They are of a special heavy railway type, with 24-foot fly-wheels, each weighing 50 tons. The condensing apparatus is of the Allis vertical type, and is independent of the engines.



A STORAGE BATTERY PLANT ON THE SOUTH SIDE ROAD

Adjacent to the main building is a rectangular cooling tower, divided internally into five vertical sections, each provided at the bottom with two 10-foot fans carried on the shaft of an 18 H. P. motor. The fan speeds may be varied by three different motor combinations. The condensing water is delivered to a distributing header 30 feet above ground level. Thence five mains distribute it into drip pipes in the several sections, where the water trickles downward over wire mats continuously fanned by the cool air blast from below. The final temperature of the water is about 85° F.

The electric generators are four 800 K. W. 12-pole Westinghouse compound-wound dynamos with large overhead capacity. The field pieces are split vertically and can be slid at right angles to the shaft, giving access to the armatures which are mounted directly upon the engine shafts. The main switch-board is made up on the panel plan, and is so fitted with instruments as to record separately all subdivisions of the power generated.

The station shows great operating economy in practice. A complete power house shift, including chief engineer and clerk, comprises nine men, five of whom rate only as helpers and oilers. Hence the labour cost is very small. The power house records show that the total cost per kilowatt-hour is less than half a cent.

The system of distribution is a modified plan of what is popularly known as the "third-rail" system. Extending from end to end of the line, on the inner side of each track and along all switches and cross overs, is an ordinary 40-pound T-rail, in 60-foot lengths, supported on insulators at short intervals, and with its surface about 4 inches above the working rail, and a few inches from it. This rail is bonded at every joint with double horseshoe bonds to provide continuity of circuit. It is known as the "power rail," forming one terminal of the electrical system, and current is taken from it by flexibly mounted shoes carried on the car trucks.

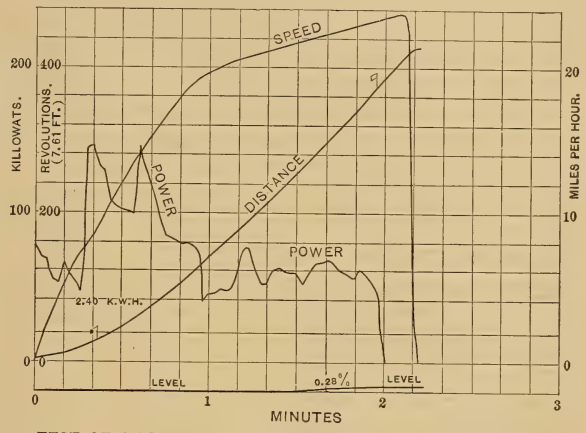
This rail is divided into sections of variable length, which, instead of being left open as has hitherto been the prac-

tice, are joined together by switches or fuse blocks so as to make the rail electrically continuous under normal conditions, but with provision for cutting out a section automatically or at will in case of short circuiting.

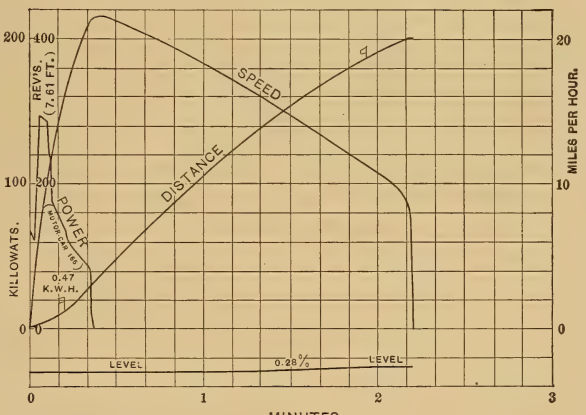
Extending each way from the power house are five feeders, carried on insulators on the centre of the structure under a housing, the majority of these feeders being connected to the power rail section by sub feeders through circuit breakers at various points. One feeder goes to a connection between the South Side system and the "Loop" for emergency, and two of the feeders are used in connection with storage batteries which are placed each at approximately half the distance each way from the power house to the ends of the line. The return circuit is made through the tracks, which weigh 90 pounds to the yard, are bonded at each joint, and cross-bonded every 120 feet.

There is also a permanent connection between the power rail of the South Side system and the "Loop" through a fixed resistance, and cars and trams in passing from one system to the other at times receive current from both stations, and they are also directly connected together at the time of transit through the shoes on cars passing over the gap.

The introduction of the storage battery on elevated railway work, which is a step in the progress towards high-tension long-distance transmission with local substations for railway operation over considerable distances, was made on the South Side road for the first time in elevated railway practice The high schedule required, the number of trains in operation, and the consequent heavy demands for current due to quick acceleration and aggregated loads produced a somewhat more marked variation in the central power plant than would occur with less severe transportation demands. The batteries act as equalisers for the central station, reduce the drop of potential on the line, add great reliability to the power supply, and, in some measure, carry a proportion of the peak load which is characteristic of elevated railway practice, where the great bulk of traffic is carried in the morning and in the evening in limited hours.



TEST OF ONE MOTOR CAR AND THREE TRAILERS. SLOW ACCELERATION TO POINT OF BRAKING



TEST OF TRAIN OF THREE MOTOR CARS. QUICK ACCELERATION; THEN COASTING. FLAGS SHOW HALF-MILE STATIONS

Each battery consists of 248 cells, of the chloride type, made by the Electric

Storage Battery Company, of Philadelphia. Each cell has 26 pair of plates, and they are carried in lead-lined tanks built for twice that number, so that the battery capacity can be easily doubled.

Each battery has a capacity of 535 kilowatt-hours at the hour-discharge rating, and can easily discharge fully 60 per cent. above this with safety. The nominal charging rate is about one-quarter that of the hourly discharge, but, of course, it can be increased when necessary. Some addition to the battery has recently been made.

The batteries are placed in multiple with the line without any booster. Their operation is entirely automatic,

TEST OF ONE MOTOR CAR. QUICK ACCELERATION; THEN SERIES RUNNING

each one acting both as a reservoir for energy and a regulator of the voltage. Of course, one practical effect is to increase the capacity of the supply system, and in operation the present battery takes the place of one unit at the station. The principal function of the present battery is to take care of quick current variations, but as soon as the additional battery is put in, more of the peak load during the heavy hours will be taken care of.

We now come to the car equipment and system of control,—the multiple unit,—which is the distinctively characteristic feature of the whole installation. It has been already pointed out that the multiple unit system is an aggregation of transportation units of variable size, each equipped with the power required to operate that unit at a given schedule and under determined conditions, with means for controlling the aggregation from two or more points. This does not necessarily mean that every car is equipped, for every other one only may be,—that depends upon the schedule and the requirements of acceleration.

Of course, the finality of the system on roads with frequent stops, to get the maximum schedule speed, is a motor on each axle, but in a large number of cases, and with pivot truck, cars commercial demands are such that two motors per car are sufficient, and, on some service, two motors on alternate cars only.

The equipment of the South Side road has been made on a mixed plan, 120 cars first being each individually equipped with two motors, then 30 cars with a "train line" but without motors, and finally 30 additional cars completely equipped.

The position and arrangement of the South Side yards, the running of trains into a Y at one end and around a loop at the other, produces every possible aggregation of cars. Hence for the equipment, in order to avoid head and tail switching, and to permit of this variable aggregation, there was one vital condition, which was that, no matter how trains were made up, like hand movement from the end of any car must at all times mean like track movement relative to the op-

erator, and the system of connections from one car to another must automatically provide for such a result.

This variation of car aggregation, and the further condition that no seat room should be taken up by the motorman, made it necessary to provide each car with a movable cab on the platform, such that it could be left open for the free use of the ordinary entrance gate when in the body of the train, and yet be readily closed and afford protection to the motorman when at the leading end, at the same time allowing free passage from one car to another. On each car, therefore, at the right-hand diagonal corners the iron work has been removed, and a three-part cab constructed, the outer end being a fixture with a drop window, and carrying in the angle formed by the platform the initial controlling mechanism, being the master controller for the electrical system, and the engineer's valves for the air brakes. On each side is a door, each hinged in opposite direction, and folding back, one over the other, against the header of the car, leaving, when in this condition, the platform clear and the ordinary gate in operation.

When used by the motorman, one or both doors are closed, the iron gate is swung in place, and a small, protecting cab is the result.

Under one end of the car, in place of the ordinary truck, is a motor truck carrying two 50 H. P. (hour rating) standard railway motors of capacity and gearing such as to safely allow the motors to work up to the skidding point of the wheels with 60 per cent. of the weight of the car equipment and load upon them. The motors are of General Electric manufacture, and of the usual Sprague suspension.

In the hood of each car is a controller for the motors, enclosed behind a trap door which can be lowered for ready inspection. The controller is of the multiple-series type, driven by a small pilot motor, and provision is made for, at will or simultaneously producing a step by step, or interrupted or periodic forward movement of the controller, and a continuous or interrupted return movement of it to the off position through automatics connected with the pilot motor and the initial control circuits.

In addition to the current varying controller, there is a main reverser,

INSIDE OF VESTIBULE OR CAB

likewise operated through the same agencies as the pilot motor, for determining the direction of the current delivered to the motors, and for instantly opening the circuit of the motors in case of emergency.

Inside of each cab is a small master controller or operator's switch mounted on a standard and fastened to the woodwork of the cab. Through this master controller the pilot apparatus of the current varying controller and the reversers are governed. It is provided with a movable handle operating a spring retracted spindle, which through various degrees of movement makes contact with the reverser circuit and with three

determinate positions, coast, series and multiple.

Momentary contacts on these various points give any desired intermediate position of the main controller, which has a stepped movement. In order to maintain the controller at any point, or to keep the governing circuits or train lines energised, the handle of the master controller must be held in position. If it be released, whether from accident or design, the spindle instantly returns to coast position, and the controller automatically returns to the off position and cuts off the current, or if the master controller be allowed to go to the centre position, the reverser is instantly opened and the controller then comes to open circuit also.

The arrangement of circuits is such that by the use of a relay and throttle, and the proper interconnection between the controlling circuits, the operator is at liberty to do about as he pleases with the master controller, and can rely upon the main controller operating satisfactorily.

For example, he can go to the series or to the multiple position, or from the last reverse movement instantly, and the controller, instead of responding instantly, responds progressively, the pilot being limited in its movements by increment of the main current to or above any definite amount.

The throttle is set just short of the skidding point of the wheels on a normal track, allowing 15 per cent. adhesion, and limits the current input to that which is required by the determined rate of acceleration. Any rate less than this can also be effected by proper handling of the motor controller, so that any movements, no matter how refined, are perfectly possible. This throttle is in the circuit of one motor only, so that it is equally effective whether in the series or in the multiple position. Although there is a master controller on each platform, their construction is such that interference with them is difficult, and has never been known to occur.

So far, the system described is that of a secondary electric control of a single controller, but by paralleling the relay and other circuits, it is evident that two or more equipments on a single car can be operated, and also that if these equipments are put on different cars, they can likewise be operated, provided means exist for properly connecting the prime controlling circuits and insuring practical synchronism of the different controls and equal work on the different motors. Where the equipments, however, are on different cars, it becomes necessary to have a "train line" and couplers, so that a governing circuit which can be energised at various points can be made up of a train line individual to either car and couplers of some kind between them.

This train line is necessarily an independent line, not being a part of the main motor circuits on any car. It can be energised, of course, from any electrical source, but for convenience the main source of supply is the one used.

The train line consists of a number of wires perfectly insulated, made into a common cable permanently located in the car and terminating at each platform in one or more couplers, in this particular case in a pair of couplers, one under each corner of the platform, these couplers being shrouded so as to prevent dirt or rain from entering them.

When trains are made up, the train lines are connected by a reversible jumper having corresponding wires, and the system is so disposed and connected that no matter from which corner the connections are made, or how the cars are reversed or altered in sequence, the circuits are automatically established so that like track movement is always assured with like hand movement of the master controllers.

The section of train line in each car is not a part of the normal controlling circuit individual to the control equipment, but is connected with it with switches which enable a severance of the two systems,—that is, the local car system and the train line,—so that no matter how trains may be made up, it is always possible to disconnect the controlling mechanism of any train for any purpose whatever.

The practical result of the system is

that every aggregation of cars, whether one or more, has the same characteristics in the matter of load capacity, motive equipment, rate of acceleration, etc., as are possible with a single car, and every combination is made without the slightest thought being given to pairing of electrical circuits.

Each car is equipped with an automatic air brake system, supplied by Christensen air compressors, with a reserve tank, and an equalising pipe running from car to car, the compressors being started and stopped automatically through an air-governed switch by fall and rise of air pressure. On each platform, alongside of the master controller, is a small engineer's valve, so that from any selected cab the air brakes can be operated with equal facility.

A balance wire runs throughout the train and is included in the same coupling that connects up the electrical train line, so that when an air governor on any car closes circuit, all compressors start and continue in operation until the last governor throws out. This is to effect equal work on the various compressors, and to maintain absolute certainty of air supply at all times.

If a train should part, three systems of automatics come into play. The reversers go to open circuit, the controllers to the off position, and the air brakes also automatically operate.

If the main circuit fails, all reversers open instantly, and the controllers must come to the off position, which they will do automatically as soon as current is restored, before current can again be put in the main motors.

So, too, if there is an instant reversal of the master controller. The reversers first open circuit, the controllers return to the off position, then start again, and are instantly arrested on the first contact. Provision is made so that it is impossible to run backward at more than half speed from any platform when operating from that platform. The cars are, of course, electrically lighted, and are also provided with electric heaters.

For several weeks, on account of lack of equipment, the motors on the equipped cars in the morning and evening hours were subjected to a regular increase of load of about one-third, and at times every motor car has been in operation. The economy of quick acceleration for high schedules has been thoroughly demonstrated. and the lower diagram on page 455 gives a section of a run which is typical of operation when coasting freely. On this test, with the car making a 15-mile schedule, and under the conditions of grade and station intervals on the South Side road, the energy used at the car was about 73 watt-hours per ton-mile.

The diagram on page 456 gives an illustration of what is often preferable practice, a quick acceleration to a somewhat lower maximum speed, and then operating motors in series to maintain a constant, or slowly diminishing speed for some distance.

These form an interesting comparison with the curve shown in the upper diagram on page 455 that of a motor car pulling three trailers, which is typical of locomotive-car practice on frequent stop service. It will be noted here that the acceleration continues to the point of braking, the most uneconomical method of operation.

A very large number of records have been taken by Mr. John Lundie, a well-known transportation expert, running into the hundreds, under all possible conditions of acceleration and all sorts of combinations of equipped and unequipped cars, for determining the best methods of operation, the highest degree of economy under various loads, and for ascertaining track, car and gear resistances, resulting in a new and most useful formula for train resistance. These tests are conclusive of the benefits of this method of operation, independent of the influence on passenger traffic of high schedule speeds and short time intervals.

The system was put to its hardest test on October 19, 1898. Operating with only 148 cars on 20 miles of total trackage, 240 cars per hour were sent into and out of the Loop at Congress Street hour after hour without a hitch. This was done by reversing trains at

crossovers at three or four different points, thus intensifying the car movement where traffic demands were greatest. At times 65 per cent. of one track on the Loop were covered by cars from three different lines.

On this particular day when the car mileage, excluding the Loop was increased about 80 per cent., and with very heavy loads, the central station had six 400 H. P. (nominal rating) boilers only in use, with but two men in the fire room, and there was no straining of engines, dynamos or batteries.

As an example of extraordinary duty, the operation during recent holidays may be cited. During a good portion of the time the central station is reported by its consulting engineers as having operated as follows:—50 per cent. overload for 6 hours, full load for 17 hours, and 74 per cent. load factor for 24 hours.

Out of 120 motor equipments designed for individual operation, 119 were in daily operation morning and night, with 28 or 29, trailers, thus overloading the machines one-third, and often these trains, coming out of the Loop from two to five minutes late, have made up time before reaching the end of the run, but naturally at a loss of efficiency because of the slower acceleration.

The average duty of this equipment is higher than that of any other elevated railway in the world. Cars have frequently made as high as 290 miles a day for days in succession, and the average maximum of cars in operation was for long periods run to nearly 100 per cent.

Financial, not alone technical results are a measure of success, and a comparison is, therefore, in order. The months of November and December, 1897 and 1898, are the first two strictly comparable months. The road then included "Loop" operation, 19.44 miles of track, in 1897 was operated entirely by steam, and in 1898 entirely by the Sprague multiple unit electric system.

In addition to all "Loop" expenses there is a rental charge equal to 10 per cent. of the gross passenger receipts of the road. This should be considered really as an interest charge, not as an operative expense.

For these two months, with an average of 489,979 car-miles on the main line, the comparative table following shows:—

(a) Ratio of expenses to earnings including "Loop" rental, taxes and licenses;

(b) Ratio of expenses to earnings, excluding "Loop" rental, but including taxes and licenses;

(c) Net earnings;

	(a)	(b)	(c)
November '97, steam	87.3	77.7	$10,603.80
" '98, electric	57.3	47.7	39,448.56
December '97, steam	83.6	73.8	14,691.69
" '98, electric	55.0	45.4	45,355.68

The succeeding months show increasing traffic and equally favourable results. The total operating expenses per car mile during November, 1898, on the main line, excluding the "Loop," including everything except licenses, taxes and rental, were less than 7½ cents on an average schedule of 15 miles an hour, with stations 2080 feet apart.

Based upon the Chicago performance, and allowing for the difference of coal cost, the Manhattan road, in New York City, now operating at from 12 to 12½ miles actual schedule during time of maximum load, and making about 43,000,000 miles annually, can be operated on the multiple unit system at an average 16½-mile schedule at not exceeding nine cents, and at the same mileage this would mean a saving, excluding interest on investment, of about $1,300,000 per annum, or allowing interest on investment, of about $750,000.

AN ELECTRIC LOCOMOTIVE ON THE AKRON, BEDFORD & CLEVELAND RAILWAY, U. S. A.

THE ELECTRIC LOCOMOTIVE

ITS PRESENT STATUS IN THE TRANSPORTATION PROBLEM

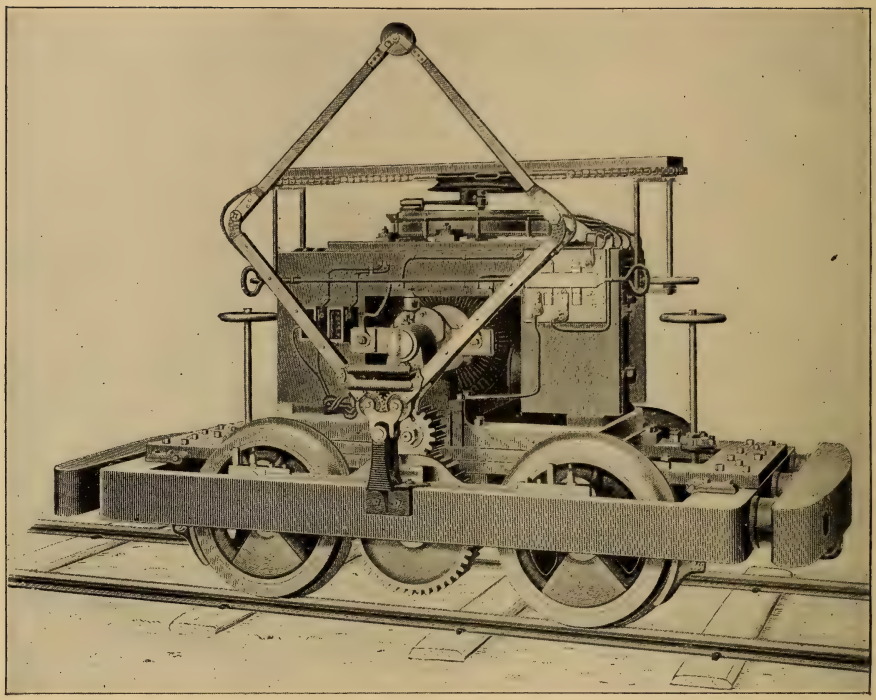
By George R. Mair

THE application of electrical energy to tractive duty, by the agency of locomotives, may be said, in a general way, to have been confined to three lines,—underground mine haulage; surface haulage systems for factories; and installations on steam roads for handling suburban traffic and switching freight.

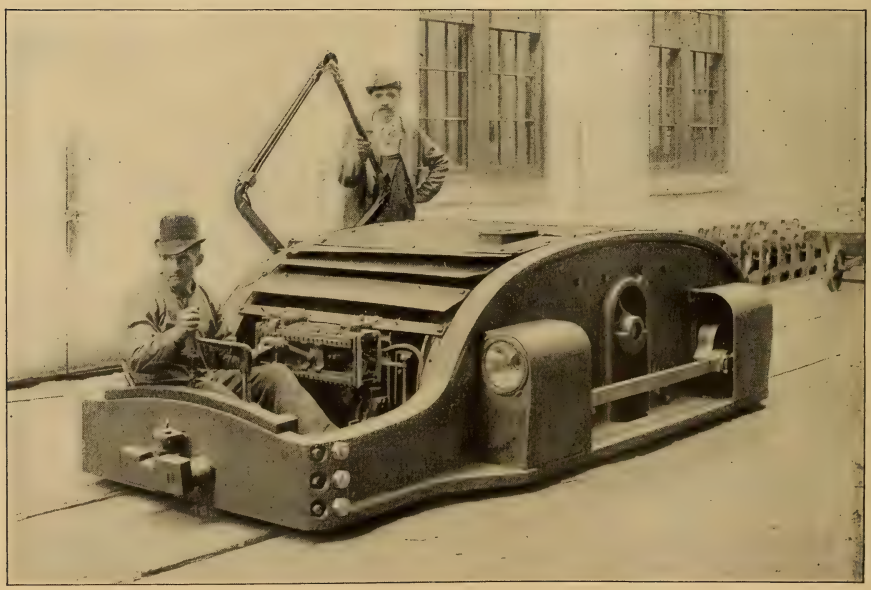
Of these divisions underground haulage deserves first consideration, for in this field the electric locomotive was first employed with commercial success, and to the experimental work in this service is largely due the present high standard of electric locomotives for other duties.

It is self-evident that in the transmission of energy by electricity, as by any other system, a point will be reached where the interest on the initial cost and the transmission loss will balance any saving which may be effected by generating at a central point all the power required for a large number of small subsidiary motors. In electric locomotive installations, however, this general statement is strongly qualified by local conditions, and it is because the electric locomotive is uniquely suited to successful operation under the severe conditions which obtain in underground duty, that its development in this field has been so rapid and its application so comprehensive.

Comparing the electric system with rope, steam, and compressed air, we find, to begin with, that the electric locomotive is free from complicated mechanism requiring careful adjustment and frequent repairs. The only friction loss is the small percentage in the ma-



AN EARLY AMERICAN ELECTRIC COLLIERY LOCOMOTIVE



THE THOMSON-HOUSTON "TERRAPIN BACK" ELECTRIC MINE LOCOMOTIVE, USED AT FOREST CITY, PA., IN 1891. THE THIRD IN AMERICA

chine itself. In rope haulage, on the other hand, a large amount of power is expended in keeping a long line of cable in motion, irrespective of the load upon it. An electric locomotive takes power only when doing work and then only in proportion to the work done. It gives off neither heat, smoke nor gas to vitiate the air, nor steam to rot the timbers in underground workings, and can run directly to the working faces.

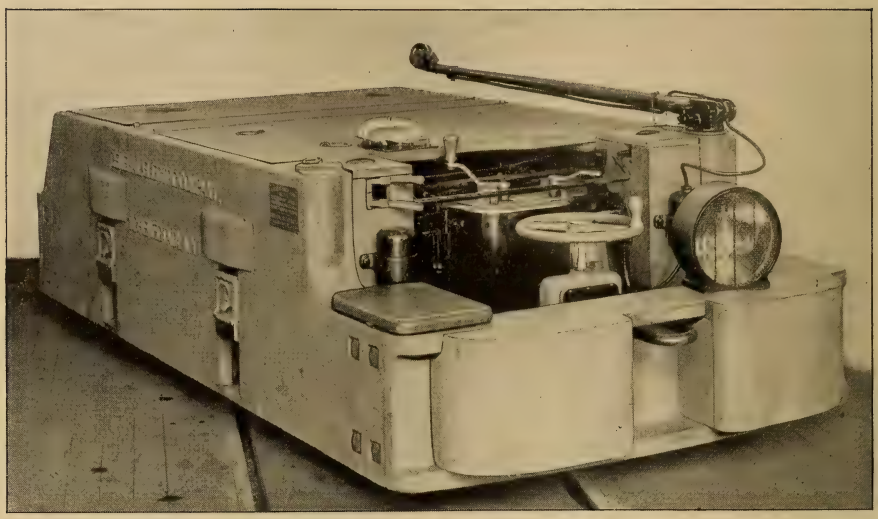
With the electric system alterations and repairs may be made at small cost. Usually the current required can be transmitted by the trolley wire alone, at a practically negligible loss, and only an inexpensive line construction is required. In this respect it compares favourably with a compressed air system involving high first cost and the considerable items of maintenance, leakage and transmission loss necessarily experienced with pipe lines and reservoirs. The vertical section of a steam or compressed-air locomotive, for a given duty, is approximately one-third greater than that of an electric locomotive, the latter being usually about the same height and width as the mine cars, and calling for no extra expense for entry driving. The electric locomotive, too, is capable of operating on curves of 15-foot radius, and consequently is specially suited to the ordinary mine tramway.

Owing to the high speed of early motors, the builders of the first locomotives were at a disadvantage. The necessary means of speed reduction involved features of low efficiency, high maintenance cost, and such cumbersome construction as to prevent the building of a compact machine. Most early machines consisted merely of a wooden truck carrying an ordinary stationary motor from which power was transmitted to the axles, either by chain and sprocket, or shafting and bevel gears. Naturally, apparatus of this character could not attain a permanent success.

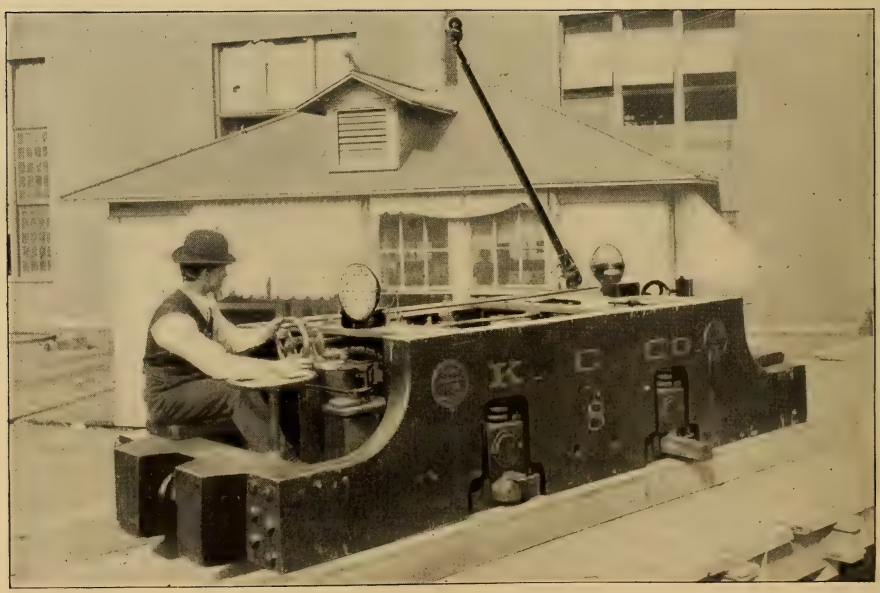
AN ELECTRIC LOCOMOTIVE AT THE PLANT OF THE WYTHE LEAD AND ZINC MINING CO., AUSTINVILLE, VA., U. S. A.

In the early days of motor building a motor of large output and comparatively small dimensions, with a safe heating-limit, was not produced, and for this reason the first mine locomotives were of the single-motor type. While this design has been generally abandoned, most of these machines gave favourable results, and many are still in operation.

The first electric mine haulage plant in America, and a peculiarly successful one, considering its early date, was in-



AN ELECTRIC MINE LOCOMOTIVE, BUILT BY THE GENERAL ELECTRIC COMPANY, NEW YORK

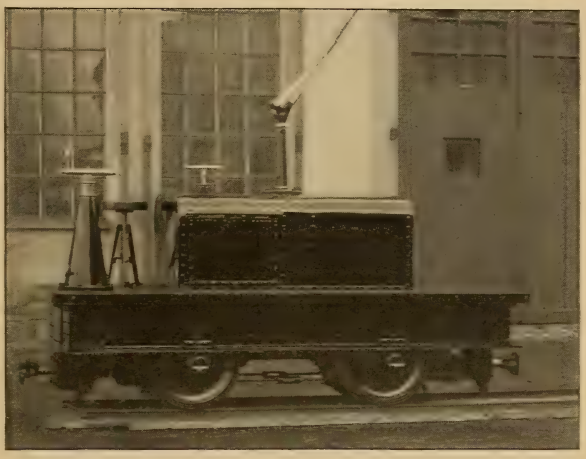


A MINE LOCOMOTIVE BUILT BY THE WESTINGHOUSE ELECTRIC CO., PITTSBURGH AND LONDON

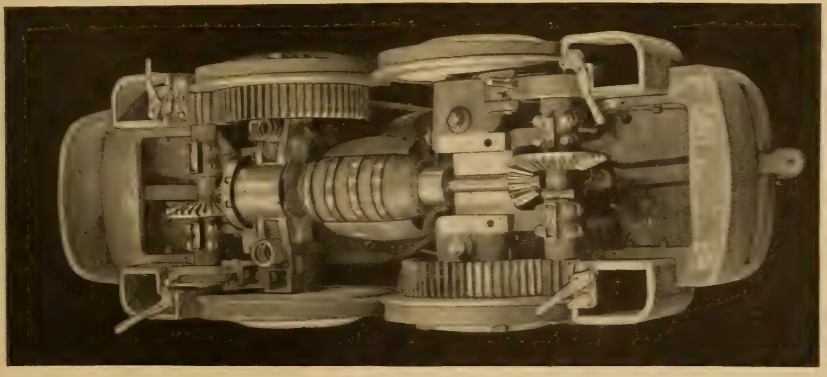
stalled in July, 1887, in Lykens Valley Colliery, Pennsylvania, U. S. A. The haul was 16,300 feet, and the locomotive weight, 15,000 pounds. The maximum trailing-load was a 100-ton trip of coal cars, hauled at a speed of six miles per hour. A grade of 1 ½ per cent. against the loaded trip was easily mounted. The minimum radius of curve was 25 feet, and the potential used was 400 volts.

The power was transmitted by pinion and gear from the armature shaft, running at 1000 revolutions per minute, to a counter-shaft carried in the field frame of the motor and running at 400 revolutions. A chain and sprocket, of special form, connected this first counter-shaft to a second one between the forward and rear wheels. Steel chains with thimbles were used from this second counter-shaft to drive the axles, upon which 30-inch drivers were mounted. Two sets of drivers, carrying the entire weight, were used. The body was a heavy wooden frame, and weight for traction was secured by ballasting with scrap iron. This plant was eminently successful, and for years, performed most creditably the duty for which it was designed.

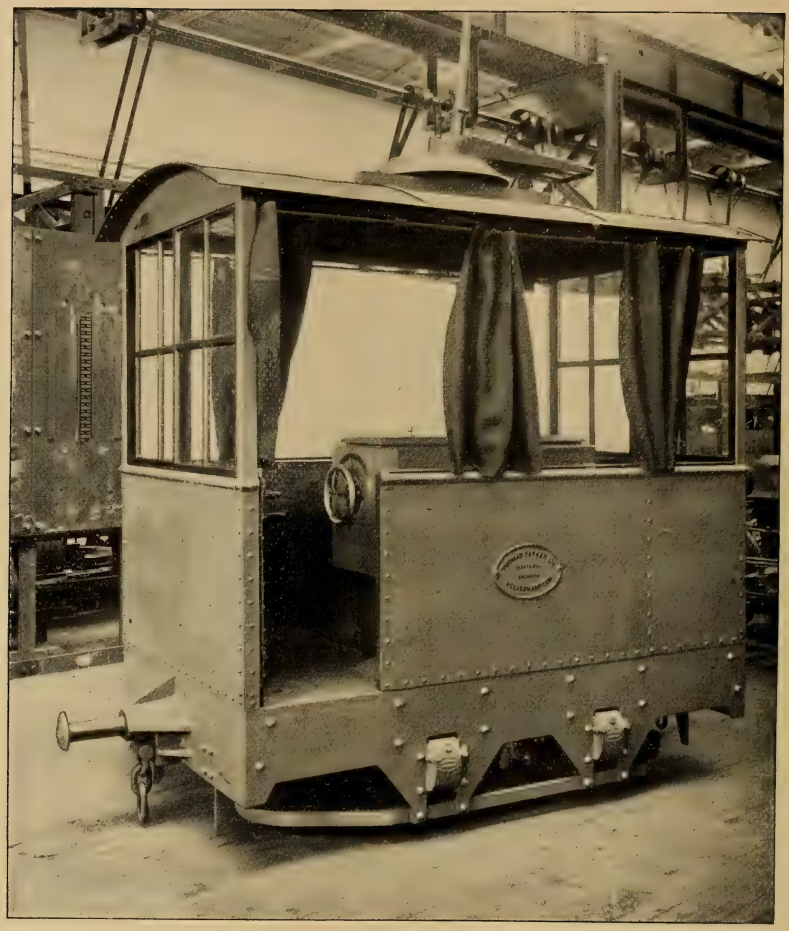
The upper illustration on page 462 shows a locomotive employed in one of the early American mine haulage plants, installed in 1889, at the Erie Colliery, near Scranton, Pa. It consisted of a 40 H. P., 220-volt motor surrounded by a heavy wooden frame-work carrying the wheels and gearing. The power was transmitted from the motor to one axle through three sets of gears, and from the first set of drivers to the second by means of connecting rods. The weight was 12,500 pounds; the speed, under full load, was six miles per hour; and the



MINE LOCOMOTIVE BUILT BY THE SWEDISH GENERAL ELECTRIC CO., VESTERAS, SWEDEN



TOP VIEW SHOWING GEARING OF A LOCOMOTIVE BUILT BY THE LINK BELT MACHINERY CO., CHICAGO



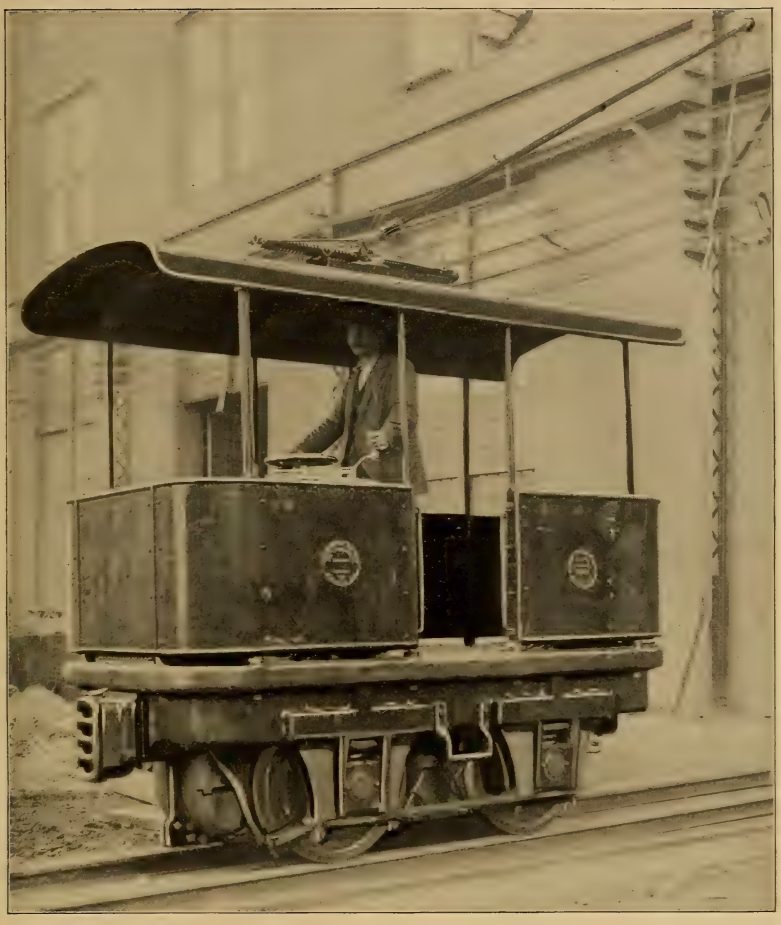
A LOCOMOTIVE BUILT FOR THE SOUTH AFRICAN GOLD FIELDS BY MESSRS. THOS. PARKER, LTD., WOLVERHAMPTON, ENGLAND

extreme dimensions were 50 inches wide, 9 feet 7 inches long and 49 inches high, with a 48-inch wheel base. This construction involved a large friction loss, and dimensions excessive for mining conditions.

The machine installed at Forest City, Pa., U. S. A., in 1891, illustrated also on page 462, showed a great improvement over previous construction. Connecting rods were still used between the drivers, but the motor was hung between the wheels and ran at a speed requiring only double-reduction gearing, while the comparative over-all dimensions were very considerably reduced.

The only important step between the Forest City machine and the present standard mine locomotive, of American manufacture, was the substitution of two motors, operating the drivers independently, in place of the single-motor construction with connecting rods.

The art of motor building soon reached a point where it was possible to build a motor of such dimensions and low speed that it could be hung between the wheels and connected to the driving axles by single-reduction gearing. The two-motor type of locomotive was then adopted, and experience has shown that the most efficient results can be secured by the independent application to the separate drivers



A BALDWIN-WESTINGHOUSE ELECTRIC LOCOMOTIVE BUILT FOR THE HAWAII ELECTRIC COMPANY, HONOLULU

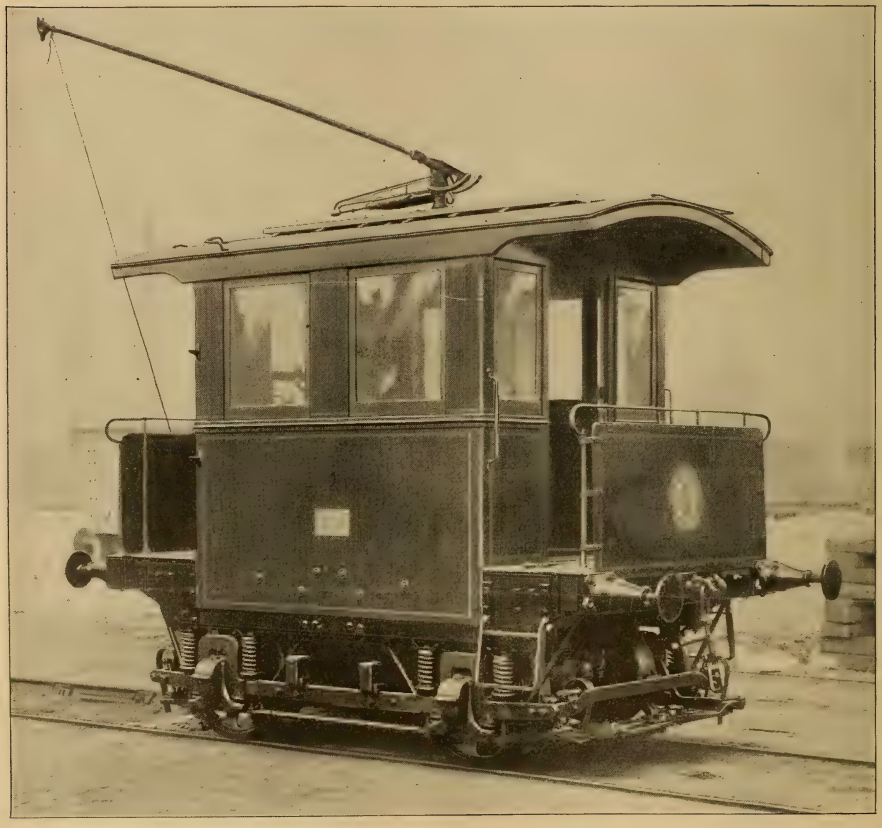
of the total power required. Locomotives of this description, having a capacity of 4400 pounds horizontal effort at a speed of 8 miles an hour, are now built for as narrow a gauge as 24 inches and with over-all dimensions of 46 inches width, 37 inches height, 146 inches length, and a wheel base of 46 inches.

The two illustrations on page 464 show the standard type of American mine locomotive, and illustrate the advance made during an almost incredibly short time. The main body of the machine, which is carried on springs, consists of side and end frames with machined joints tied with heavy bolts. In order to bring only the minimum amount of wear and tear on the track and road-bed, the working parts are made as light as is consistent with proper strength, and the additional weight necessary for traction is put into the frame. One motor is hung on each axle and drives it through single-reduction gearing. The cast steel field-frame of the motor forms a dust and water-proof case. The gear and pinion are covered by a dust-proof case filled with grease. This construction naturally means a very long life both for the motor and for the gearing.

A special form of brake is generally used, consisting of a vertical, threaded

shaft, rotated by a hand-wheel. This shaft raises and lowers, by means of the thread, a nut to which the brake-chains are attached. With this arrangement it is possible to skid the wheels with a very slight exertion, and the brake being locked in any position, the necessity for pawl and ratchet is obviated. A magnetic blow-out controller regulates the motors by cutting out and throwing in resistance in the motor circuit, a purely rheostatic control being necessary, as the well-known series-parallel method cannot, under usual conditions, be applied to mine locomotives. The illustrations show the massive character of the machines and the thorough protection afforded the working parts. Damage of any serious nature, due to fall of roof, derailment, collision, or other ordinary accidents of mining practice, is almost unknown.

In discussing the development of the mine locomotive, reference has been made especially to American practice, for the reason that in America this development has proceeded along well defined lines and reached a standard type of machine, generally adopted by all makers. In apparatus of this class in the United Kingdom and on the European continent there is a wide difference in design even between machines turned out by the same shops. This is, perhaps, because manufacturers there have been obliged, in many cases, to conform to purchasers' specifications, whereas in America the design has almost invariably been left with the makers, the users specifying



A LOCOMOTIVE BUILT BY MESSRS. JOHN FOWLER & CO., LTD., LEEDS, ENGLAND

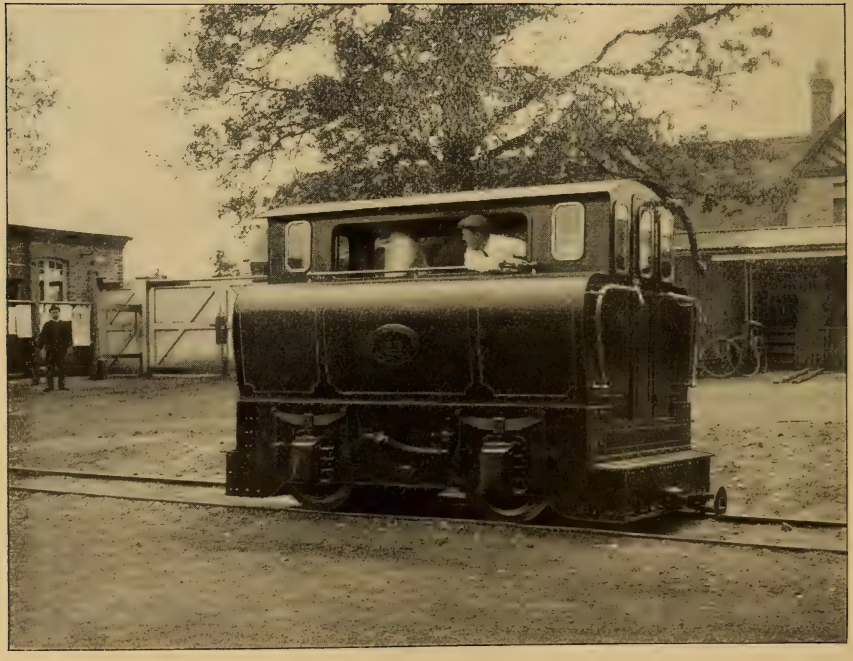
ONE OF THE LOCOMOTIVES BUILT BY MESSRS. SIEMENS & HALSKE, BERLIN, GERMANY

only duty and operating requirements.

The pioneer manufacturers of electric mine locomotives on a comprehensive scale were Messrs. Siemens & Halske, of Berlin. In 1882 they equipped the Royal Coal Mines at Zaukerode with a locomotive designed to haul a train of ten cars having an aggregate weight of about eight tons, handling this load over the mine tramway at a speed of about 4½ miles an hour. In actual practice, however, the usual load was

AN INDUSTRIAL ELECTRIC RAILWAY EQUIPPED BY ARTHUR KOPPEL, LONDON, BERLIN AND NEW YORK

A LOCOMOTIVE WORKED BY STORAGE BATTERIES. BUILT BY THE FULLER-WENSTROM ELECTRICAL MFG. CO., LONDON

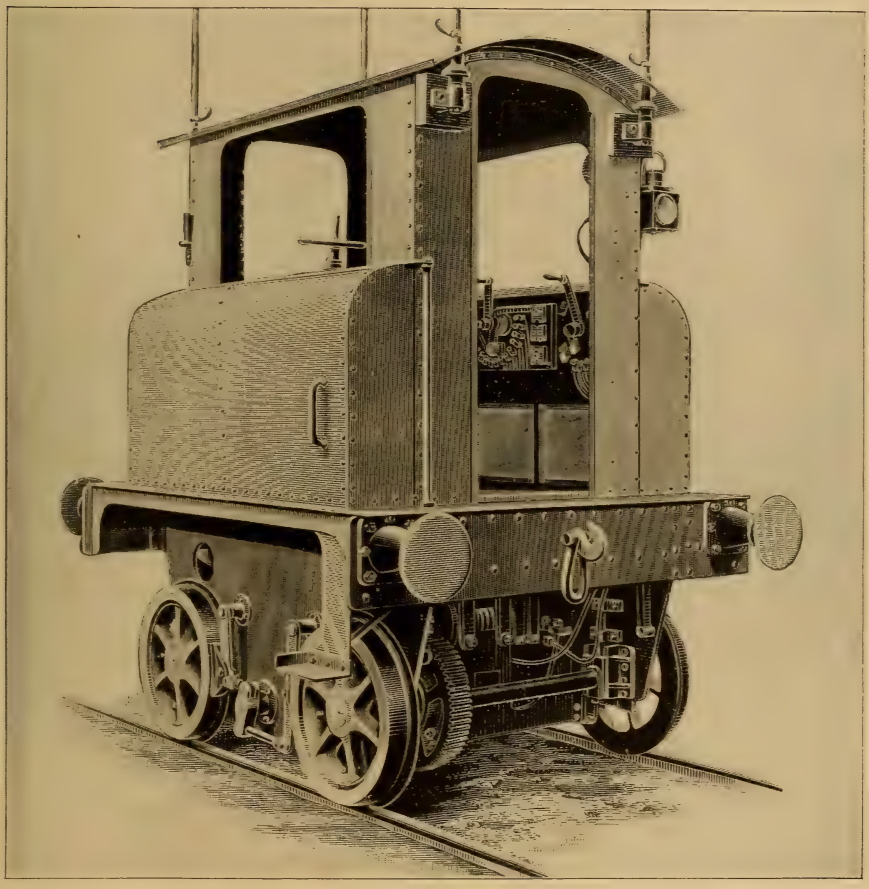


LOCOMOTIVE BUILT BY MESSRS. CROMPTON & CO., LTD., LONDON

fifteen cars, or an aggregate weight of about twelve tons. This equipment was the first successful mine haulage plant in the world. The locomotive was of the single-motor type, and although the construction would to-day be considered crude, it hauled satisfactorily an average of 700 to 800 cars per day,—the work for which it was designed. It is still in successful operation, although, of course, improvements and substitutions have been made.

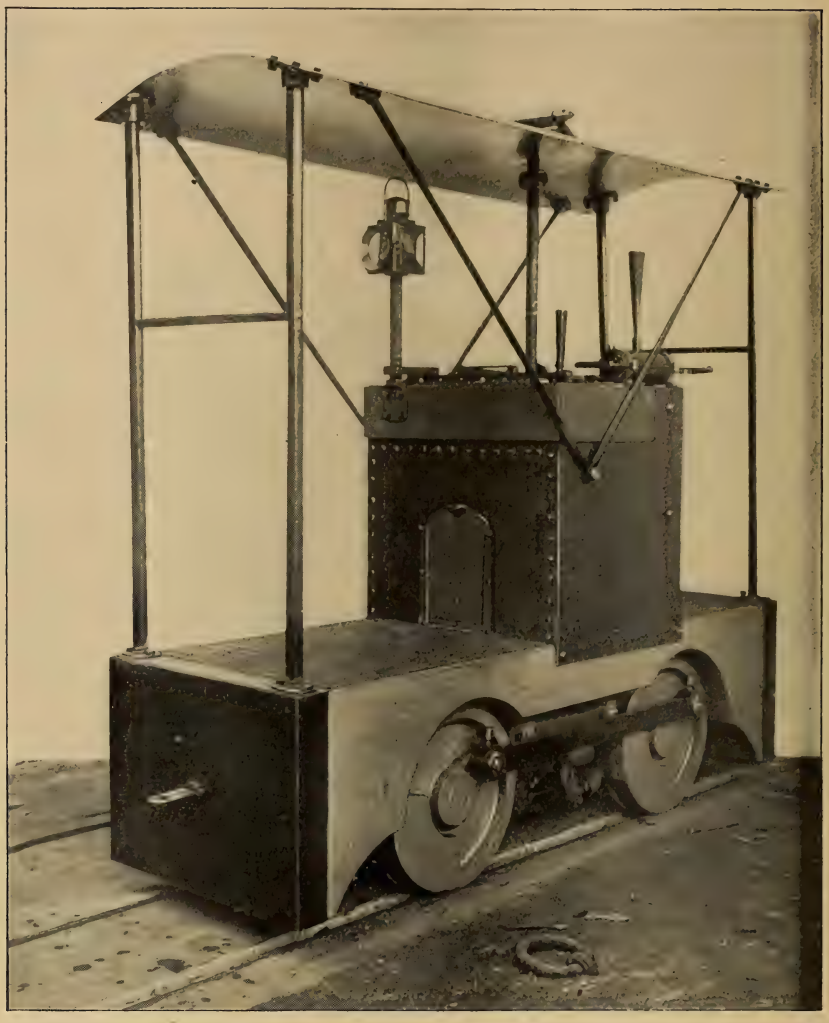
The mine locomotives installed by this progressive firm for the New Stassfurt Salt Mine Company in 1882; in the coal mines at Beuthen in 1883; and in the Ashio Copper Mines, in Japan, may be mentioned as among the very earliest successful applications of electric power to this class of work.

Swedish manufacturers were among the first in the field, and as early as 1890 the Allmänna Svenska Elektriska Aktiebolaget, of Vesteras, had two locomotives in successful operation. These machines weighed 10,000 pounds each, and were of the single-motor, double-reduction type. Over a tramway 6700 feet long, with gradients of 2.2 per cent., loads of 14,000 pounds were hauled at a speed of 5 miles an hour.



AN ELECTRIC SHUNTING LOCOMOTIVE FOR IRON WORKS USE, BUILT BY MESSRS. MATHER & PLATT, LTD., MANCHESTER, ENGLAND

The position of the electric locomotive amongst general mining apparatus is illustrated in the South Africa gold



A LOCOMOTIVE FOR CONTRACTORS' USE, BUILT BY MESSRS. ERNEST SCOTT & MOUNTAIN, LTD., NEWCASTLE-ON-TYNE, ENGLAND

fields. The discovery of these fields is so recent that the equipments for working them naturally afford examples of the highest development in the special class of machinery required. In one of the first systems of mechanical haulage on the Rand electric power was adopted. Two locomotives of British make were installed at the Village Main Reef Mine, where they have been in operation for a number of years. While these machines are not used for underground service, their general construction is of the character employed for mine locomotives, and the results shown have been so excellent in this, the first plant in the Johannesburg district, as to warrant the belief that in the near future the electric system will be generally adopted on the Rand.

It is of interest to note that electric mine locomotives are in operation in almost every European country, and in China, Japan, Australia, the Sandwich Islands, South Africa, Chili and Mexico. There are approximately 350 at work in the United States alone. The large number of these installations and

the wide variation in the conditions under which they are successfully operating, the infinitely greater number of mines yet unequipped, and the yearly increase in the production of these machines, leave no room for doubt that the next few years will show a remarkable progress in the application of the electric locomotive to mining work.

The field covered by the second division, — surface haulage, — although wide, is, perhaps, less interesting than the first or the third. The conditions are less severe, and the solution of the problems involved is less difficult.

The small electric surface truck finds its principal use in large manufactories, where, as the modern practice is to distribute the work among a large number of buildings, some system of haulage, at once free from objectionable features, of small first cost, and reliable, safe and economical in operation, is essential. Insurance rates must not be unfavourably affected, and possibility of damage to goods in process of manufacture must be avoided ; hence, for indoor work, steam cannot be considered, and a system which cannot be operated over the entire tramway leaves much to be desired.

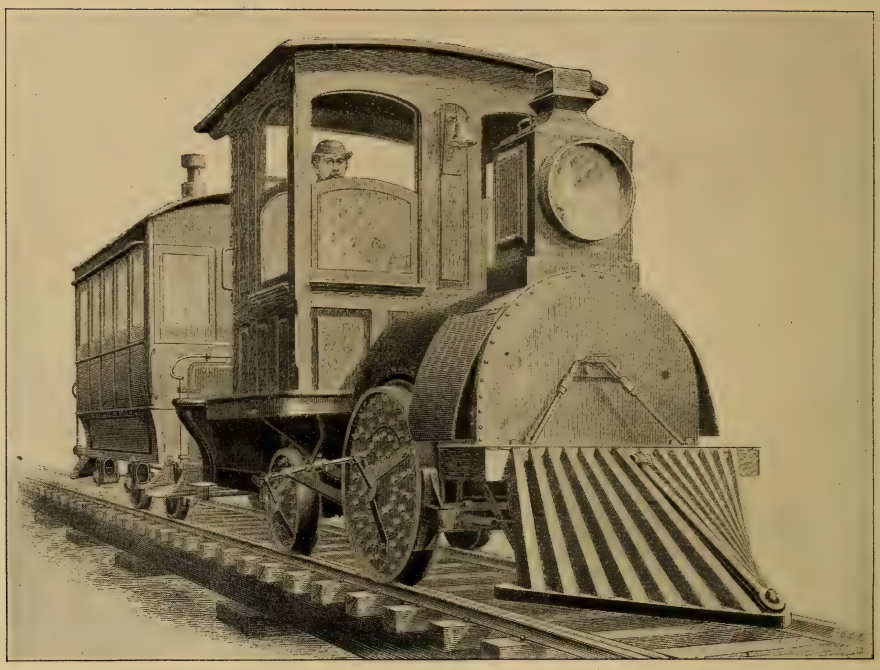
An electric locomotive is more economical than a cable system, but its principal advantage is that the loads may be handled on spur tracks and in either direction on a single main line. As the cable always moves in one direction in a rope-haulage system, two tracks, of course, are necessary for moving the loads in opposite directions. It is evident that in many cases this system is impracticable, and in all cases more expensive to install than an electric system.

Another inherent advantage of an electric system is that the locomotive is usually only one of many applications of the power about the shops, and uses but a small percentage of the total current generated for all purposes. Hence, the haulage is performed at a very small cost per horse power. Figures from a large number of factory and similar installations show that where electricity has replaced other systems, a saving of from 25 per cent. to 33⅓ per cent. has been effected, aside from the increased convenience and the absence of objectionable features.

For this service a large number of machines have been built, the general character of which is so clear from the illustrations accompanying this article that a detailed description is

LOCOMOTIVE BUILT BY THE SWEDISH GENERAL ELECTRIC CO , VESTERAS, SWEDEN, SHOWING ONE OF SEVERAL FORMS OF TROLLEY IN CURRENT USE ON THE EUROPEAN CONTINENT

superfluous. The usual construction consists of a heavy wooden platform, provided with buffers and draw-head at both ends, and equipped with controller,



EDISON'S ELECTRIC LOCOMOTIVE, 1880

brake and trolley pole. A part of the material to be transferred may be loaded upon the truck platform. This is, indeed, the usual practice, and the weight of this load is considered in figuring the total weight necessary on the drivers for obtaining the full load draw-bar pull. By this method considerable economy of operation is possible, as the weight of the locomotive may be proportioned to any particular trailing-load and no power is wasted in carrying unnecessary weight on the drivers when hauling light trains.

A heavy truck supports the platform and carries the motors and brake mechanism. Two motors, similar to those for mine locomotives, are used, supported at one end by the axle, and at the other by the truck, through a cross-bar and spring-suspension. Suitable resistance, a powerful toggle-brake, and sand-boxes, complete a piece of apparatus simple, efficient and of wide application.

Undoubtedly the modern standard-gauge electric locomotive for heavy duty is, *per se*, the finest piece of apparatus produced for this service. It is a far cry from the first machines built by Siemens, Edison, Daft, and Field, in the late seventies, to the present highly perfected type, performing, as routine duty, work which, a few years since, would hardly have been placed within the possible scope of this class of apparatus, except by the most fanciful imagination.

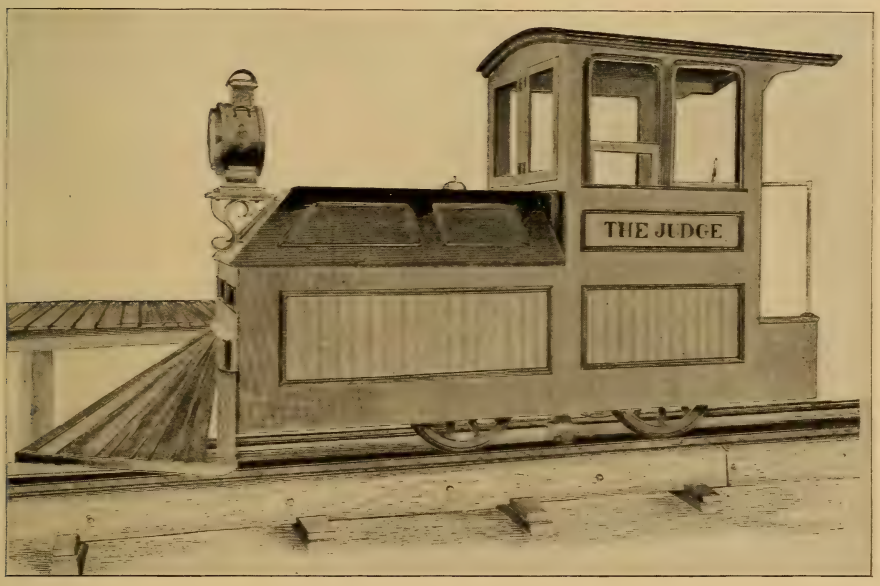
Contrary to the experience in the other branches of the application of electric energy, the development in this field has by no means been accomplished along gradually progressive lines. During a number of years experimental machines were built and operated in Germany, America, Great Britain and France, but none attained permanent commercial success. Meanwhile, the general art was rapidly advancing, and almost without warning, —certainly without any basis of expectation from previous experiments,—installations were made which have proved unreservedly successful from the day they were first put in operation.

The locomotive built by Siemens at

Berlin in 1879 was the first machine to demonstrate the fact that great possibilities lay in the application of electric power to tractive service. In October, 1883, Leo Daft's locomotive *Ampère* was in operation on the Saratoga, Mt. McGregor and Lake George Railroad in New York State, U. S. A. Peculiar features of this, the first successful standard gauge locomotive in America, were the regulation of the speed by commutation of the field windings, and the use of pendulum type electric brakes.

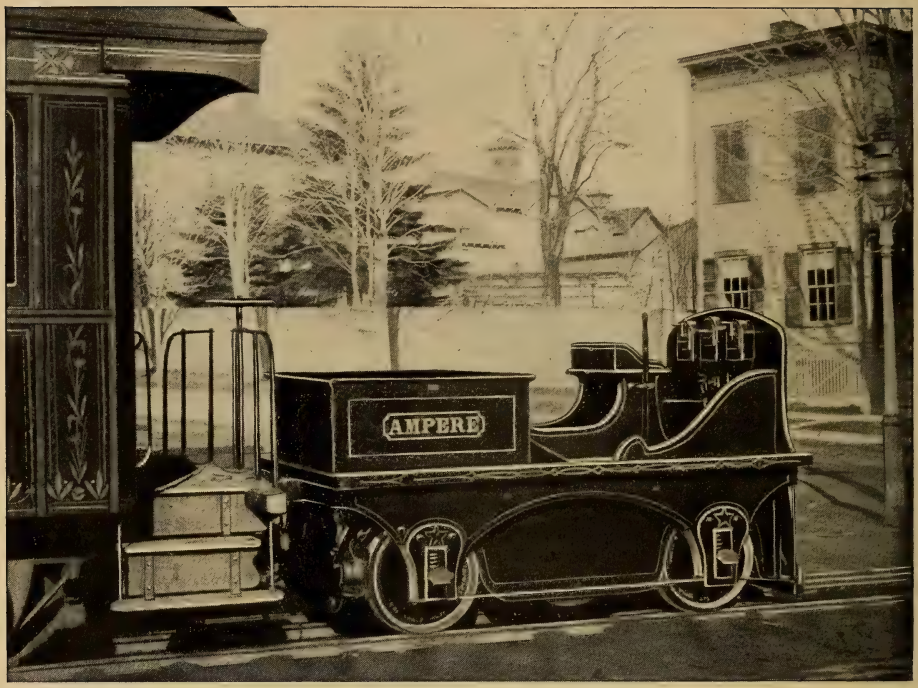
In 1885 the same inventor built a second locomotive, the *Ben Franklin*, and operated it for several weeks on the Ninth Avenue Elevated Railway in New York City. This machine was rebuilt in 1888, and was then the most powerful electric locomotive in the world. It ran regularly, for nearly eight months between the frequent steam trains, without deranging the time schedule of the road, hauling regular four-car trains (each car weighing 10 tons) over a round-trip distance of four miles, including a long gradient of approximately 2 per cent. The maximum speed was 28 miles an hour, and the minimum,—on the heaviest grade, —7 miles. While these results were most creditable, the magnitude of the problems involved in substituting electric for steam power on the New York elevated railways, was so great that nothing was done beyond experimental work.

Space forbids mention of many experimental locomotives built in America, Great Britain, Germany, France, Sweden and Switzerland, but the Heilmann locomotive, built by the Electric Traction Society, of Paris, in 1895, demands notice, because of its unique character. A complete electric plant mounted on wheels was an idea probably never before conceived, nor has its materialisation since been attempted. The question of transmission was entirely eliminated, as a single truck carried boiler, engine, generator, and motors.



THE ELECTRIC LOCOMOTIVE "THE JUDGE," SHOWN AT THE CHICAGO RAILWAY EXPOSITION IN 1883

It was calculated that a locomotive of this type, costing £6000, and having an output of 1500 H. P., would be capable of hauling a 50 per cent. greater trailing load at 50 per cent. higher speed than a steam locomotive of equal weight and engine capacity, and that



LEO DAFT'S ELECTRIC LOCOMOTIVE "AMPÈRE," 1883. THE FIRST SUCCESSFUL STANDARD GAUGE ELECTRIC LOCOMOTIVE IN AMERICA

DAFT'S LOCOMOTIVE "BEN FRANKLIN" ON THE NEW YORK ELEVATED RAILWAYS IN 1885

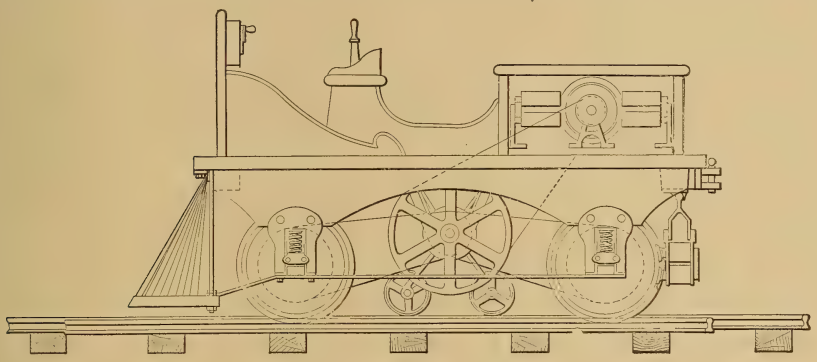
this result would be obtained through the use of a large and economical boiler, on account of few working parts and consequent small friction losses, by the application of a system of motor control which varies the current in proportion to the draw-bar pull and the voltage in proportion to the speed, and avoids losses in dead resistance; and because of the possibility of running the engine (driving the generator) at full speed and output irrespective of the grades. In this last feature it possessed, of course, a very great advantage over the standard steam locomotive.

The close of the year 1890 marked the first permanent invasion of the field of steam-railroading by the electric locomotive. In December of that year the City and South London Railway, which at intervals of 3 to 4 minutes. Both locomotives and cars are equipped with air and hand brakes, the latter only for emergency use. Some dimensions of the locomotives are:—

Length over all	14 ft.
Height from top of rail	8 ft. 5¼ in.
Width	6 ft. 3 in.
Wheel base	6 ft.
Diameter of wheels	27 in.

The initial line, entirely underground, was 3½ miles in length, and included curves of 99 feet radius, and gradients of 3.33 per cent.

The installation made by the General Electric Company, of New York, in 1895 at Baltimore, U. S. A., for hauling the regular passenger trains of the Baltimore and Ohio Railway a distance of 14,500 feet through the city, involved the use of the largest electric locomo-

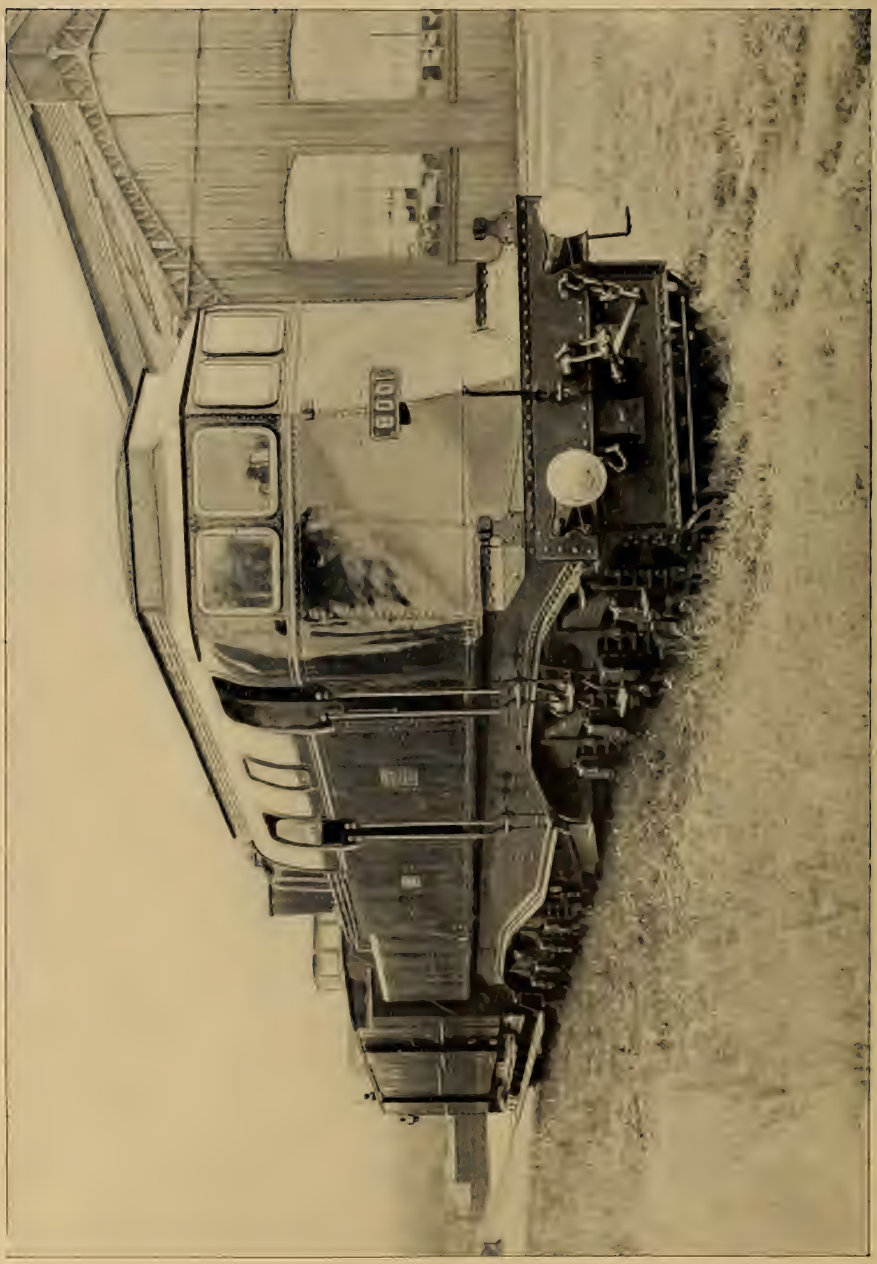


ELEVATION OF THE "AMPÈRE"

is treated of at length in another article in this issue, was opened to the public. The first sixteen locomotives furnished for this installation possessed many features which are characteristic of the best modern practice. The gauge is 4 feet 8½ inches, and the weight of each locomotive 20,700 pounds. Each locomotive is equipped with two 50 H. P. motors of the gearless type, the axles forming the armature shafts. The axles also carry the lower end of the field frames, the upper ends being supported by a flexible link connection. Three-car trains, having an aggregate weight of 40 tons, with passengers, are hauled at an average speed of 13.5 miles an hour, and a maximum of 25 miles an hour, running tives ever put in operation. From the illustrations on pages 480 and 481 it will be seen that the locomotive is mounted upon two four-wheeled trucks, and each truck is equipped with two motors. The total weight on the eight drivers is 192,000 pounds. The following are some of the principal dimensions:—

Gauge	4 ft. 8½ in.
Diameter of drivers	62 in.
Length over all	35 ft.
Height above rail	14 ft. 3 in.
Wheel base of each truck	6 ft. 10 in.
Width	9 ft. 6¼ in.
Draw-bar pull	42,000

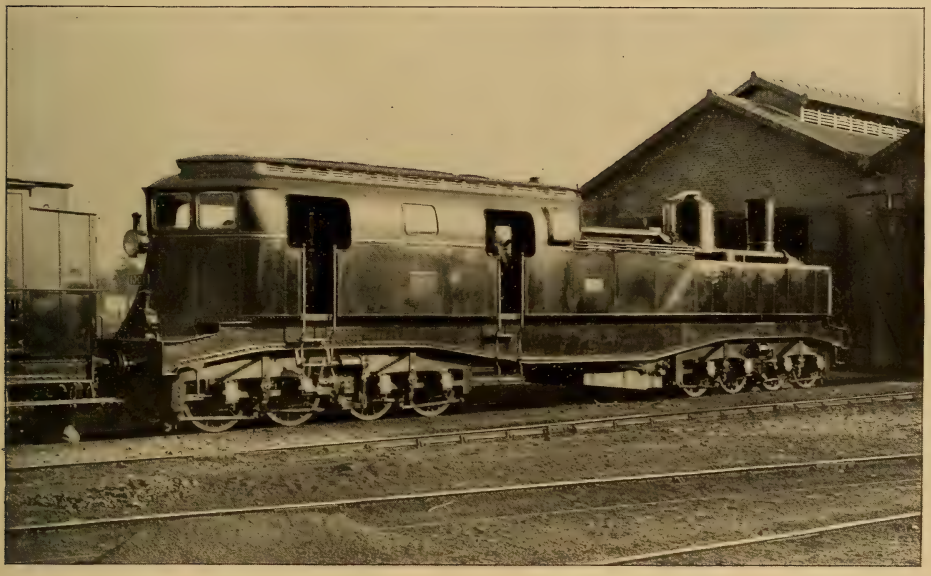
The four motors are gearless, and the armature is carried on a sleeve. Spiders are shrunk on the ends of this sleeve, and the drivers are rotated by the spider-arms which project between the



THE HEILMANN ELECTRIC LOCOMOTIVE. BUILT BY THE ELECTRIC TRACTION SOCIETY, PARIS

spokes and are provided with double rubber cushions. Each motor has an output of 360 H. P., or a total of 1440 for each locomotive. These locomotives are provided with sand-boxes, automatic air driver and train brakes, air whistle, and all the controlling equipment necessary for performing the duty of a standard steam locomotive.

In the City & South London locomotives, previously mentioned, air for operating the brakes is stored in two reservoirs, having a capacity of 16½ cubic feet, which, after each trip, are charged at a pressure of 80 pounds.



ANOTHER VIEW OF THE HEILMANN LOCOMOTIVE

The Baltimore & Ohio locomotives are provided with oscillating air-pumps driven by motors to which current is supplied from the trolley line. An automatic device starts or stops the motors as the pressure in the air tank varies.

About 7500 feet of the haul is against a continuous grade of 0.8 per cent., and there are adverse gradients as great as 1½ per cent. on 10 degree curves. A single electric locomotive has pulled over this road, at a speed of 35 miles an hour, a train weighing 500 tons, and, under test, a train of 1900 tons weight, at a speed of 12 miles an hour. This latter performance is especially interesting, as the locomotive started the train against the grade, with all the draw-bars stretched, exerting a draw-bar pull of 63,000 pounds. These machines were so well designed and the plans of the engineers so thoroughly carried out that four years of constant service have not shown the necessity for change in construction.

While the Baltimore & Ohio plant is frequently referred to as the best illustration of the applicability of the electric locomotive to standard gauge duty, a more recent installation has, perhaps, greater meaning in considering the possibilities of this field. In the early part of 1898 the question of substituting electric in place of steam locomotives for handling freight and passenger traffic between Buffalo and Lockport, in New York State, U. S. A., was under consideration. The distance between the two cities is about 18 miles. The gauge is standard, and the road is entirely on the surface. There are no local conditions which favour electric more than steam locomotives, yet after a thorough and unprejudiced investigation, electric-

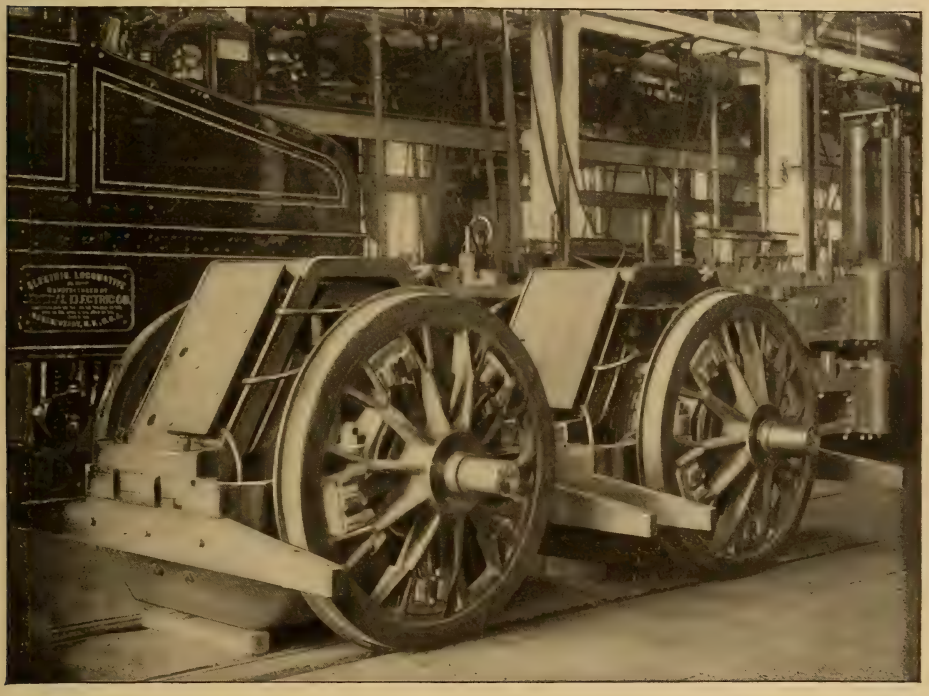
ONE OF THE THREE 90-TON ELECTRIC LOCOMOTIVES BUILT BY THE GENERAL ELECTRIC CO., OF NEW YORK, FOR THE BALTIMORE & OHIO RAILROAD TUNNEL SERVICE AT BALTIMORE, MD., U. S. A.

ity was adopted because it was considered superior for the work.

Two locomotives, similar in design to the Baltimore & Ohio machines, are now employed on this road. The main platform, carrying a cab of the usual design, is built up of 8-inch channel iron, and has heavy oak buffer beams at each end, to which the draw heads and pilots are attached. The two swivelled trucks under this platform have frames of forged and rolled iron, and pedestals of cast steel. They have pole with each other as desired. The general dimensions are:—

Length over all	32 ft.
Extreme height above rails	12 ft.
Wheel base (each truck)	6 ft.
Distance between truck centres	13 ft.
Weight	36 tons.

In addition to air-pump, air-brakes and the same general controlling and auxiliary equipment as that of the Baltimore & Ohio machines, these locomotives are provided with a special pneumatic device for handling the trolley, enabling the operator to reverse the



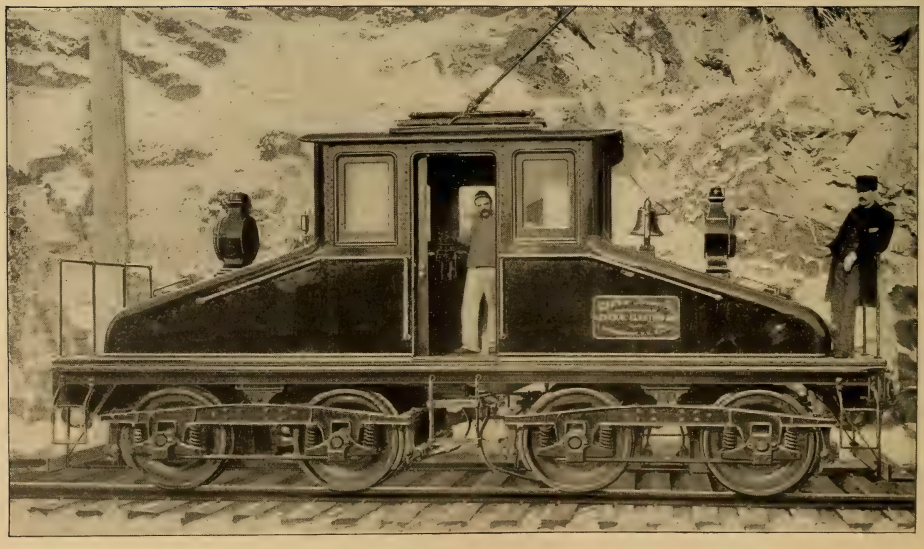
ONE OF THE TRUCKS OF THE LOCOMOTIVE SHOWN ON THE OPPOSITE PAGE

swing bolsters, supported by elliptical springs, and the truck proper rests on coil springs carried by equalising bars. The eight drivers have steel rims, are 36 inches in diameter, and are mounted on 5¼-inch axles. Each axle is driven through single-reduction gearing by a motor of 160 H. P., wound for 500 volts. High speed not being desired, the controller is so designed that two motors are always in series, and the two pairs are thrown in series or multi-

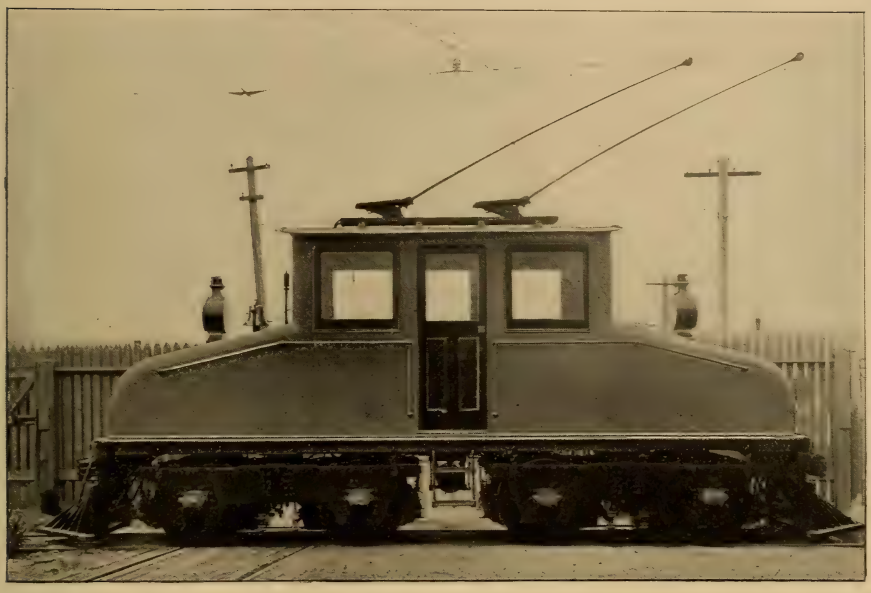
pole or replace the wheel on the wire without leaving the cab. The upward pressure is effected by a spring in the usual way, and a downward motion is obtained by a cylinder and piston, the latter compressing the spring on the admission of air. The pole is mounted on a swivel plate rotated by hand. The regular duty of this locomotive is the hauling of a 340-ton train at a speed of 15 miles an hour.

The possibility of commercially suc-

AN ELECTRIC LOCOMOTIVE ON THE BUFFALO & LOCKPORT RAILWAY. BUILT BY THE GENERAL ELECTRIC CO., NEW YORK



ELECTRIC LOCOMOTIVE ON THE SHORE ROAD, HOBOKEN, N. J., U. S. A. ALSO BUILT BY THE GENERAL ELECTRIC CO., NEW YORK



A GENERAL ELECTRIC COMPANY 40-TON LOCOMOTIVE AT TAFTVILLE, CONN., U. S. A.

cessful plants similar to the Buffalo and Lockport installation, for handling traffic over comparatively long distances, is strongly suggested by a recent trip from Boston to New York. The distance between these two cities by steam road is 233 miles, and express trains make the run in 5 hours, the fare being $6. The object was to make the trip, so far as possible, on electric roads. By the route followed the distance was about 275 miles, and there were but four breaks in the electric system (aggregating only 57 miles) where it was necessary to use other means of conveyance. By the early part of 1900 street railway lines will be in operation between the points at present unconnected, and it will be possible to travel the entire distance of 275 miles by electric road. The time of the trip was 49 hours, but no attempt was made to accomplish it in less, 26 hours being spent at various points along the road, and only 23 in actual traveling. Hence the journey was made at an average rate of about 12 miles an hour, although on certain sections it was as high as 30 miles. The total cost for transportation was $3.36, the charge on the 57 miles of steam road being $1.16, and on the 218 miles of electric road $2.20. No special arrangements whatever were made for the trip, the travelling being done

INTERIOR OF CAB OF THE ELECTRIC LOCOMOTIVE AT HOBOKEN

AN ELECTRIC PASSENGER LOCOMOTIVE BUILT BY MESSRS. SIEMENS & HALSKE, BERLIN

simply on the regular cars running on schedule time.

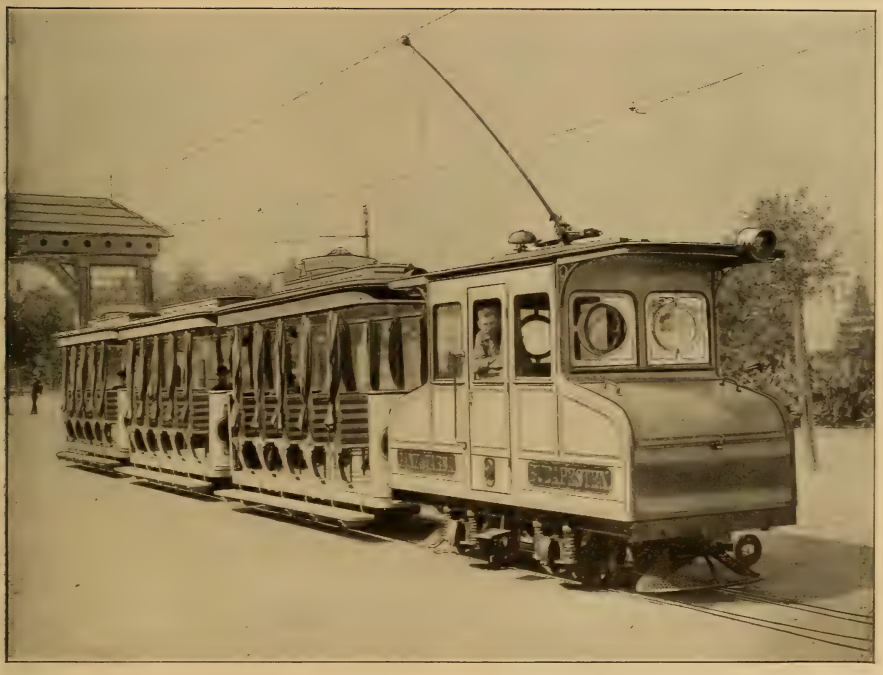
Of course, the line of the above route is well populated, but there are thousands of sections in America and in the United Kingdom and Europe where equally favourable conditions exist. The many companies forming the links of the chain stretching between these two cities are comparatively small, handle passenger traffic exclusively, and operate over short lines; yet, all are dividend earners. It does not seem unreasonable to believe that by consolidating these independent companies in a single organisation; concentrating the generator capacity in a few stations, where the high efficiency of large units would be obtained; supplementing local service by through trains; and handling freight as well as passenger traffic, such economy of operation and increase of revenue would be effected as would make long-distance electric railroading easily practicable on a profitable basis.

While the evolution of the electric locomotive, apart from the complementary equipment necessary for its operation, has, in a remarkably short time, resulted in a highly efficient machine, the limiting feature in its general application has been the transmission of energy for its operation.

Storage battery locomotives are not yet a factor of any especial importance in the field of electric traction, and hence a trolley is still indispensable. Special forms of trolley construction are, of course, required to meet arbitrary conditions, as in the case of the New York City surface railways. There the current is carried by insulated rails, supplemented by feeders, both being laid in a conduit in the centre of the track. The circuit between these insulated rails and the track (used for return) is completed through the motors by a sliding brush carried on an arm passing through a slot at the top of the conduit. The capacity of this arrangement to operate under adverse conditions was demonstrated during the winter of 1898 when these roads ran almost without interruption through exceptionally heavy snows. For city installations this form is undoubtedly superior to any yet devised.

The two systems in general use, however, are the overhead-conductor with

under-running trolley and the third-rail with sliding-contact. The former is now more prevalent, and for many conditions more desirable. Except in a very few instances, it is the only practicable system for mining work. With European manufacturers it usually takes the "loop" form, while in America the "trolley wheel" is universal. For interurban lines, if the hauling units are comparatively small and the speed not greater than, say, 40 miles an hour, its superiority has yet to be disproved.



A LOCOMOTIVE BUILT BY MESSRS. GANZ & CO., BUDAPEST

When the problem of supplying current to heavy-duty locomotives is approached, however, difficulties are encountered which preclude the use of the overhead conductor. A heavy current must be picked up at a very high speed. The matter of speed would not be a serious objection to the use of the ordinary under-running trolley, but an impracticably large number of collectors would be required for picking up the necessary current. An overhead system involving a sliding shoe having sufficiently large surface of contact would be extremely unsightly and costly.

The third rail offers a solution of the question, to which little, if any, objection can be made. This system, employed for operating the earliest experimental locomotives, but subsequently receiving little attention for a number of years, is now finding wide application. That it is the ideal plan for elevated roads goes without saying. The many doubts expressed, not very long ago, of its success in connection with surface roads, have proved entirely groundless under conditions of wide variation. Among the many successful installations using this system are the City & South London underground, the Chicago Elevated Railway and the New York, New Haven & Hartford surface roads. These, and many other plants, have demonstrated that the question of insulating the third-rail is not a serious one, and that the danger to life is slight.

Recent experiments indicate the ap-

plication, in the near future, of alternating-current motors to tractive purposes, but in considering the transmission question on the basis of what has actually been accomplished with commercial success, the necessity of using direct-current motors on the locomotive is the important factor. Owing to the difficulty of insulating the commutator segments and the consequent impossibility of building direct-current apparatus for a high voltage, the area is comparatively small over which energy can be transmitted by a direct-current plant. This condition confined the application of the electric locomotive within narrow limits until the advent of multiphase alternating-current apparatus revolutionised the electrical transmission of energy. A plant like that installed on the Santa Anna River, in California, U. S. A., operating at 33,000 volts and making 4000 horse-power available to the city of Los Angeles, 80 miles from the generators, at a transmission loss of only about 10 per cent., is a forceful suggestion of what may be accomplished along these lines in the future. One who should set a limit to the magnitude of these possibilities or the rapidity of their development would find in the recent record of the art little ground for his position.

A trunk-line road, having for its equipment revolving field generators of large capacity, transmitting alternating current at a high potential through rotary-converters located at intervals along the line, to heavy locomotives operating on the third-rail system, is a fascinating proposition. That it is not an impossible one is suggested by recent installations, notably in New York City, where apparatus of this description supplies current to the surface street railways.

In judging the future of the electric locomotive, it can not be assumed that the past affords a basis of much value. The development of electric traction has worked a revolution in the conditions of life, world-wide in scope, and of immense beneficial effect, and this within so short a period as to come within the personal observation of those who conceived the first rudimentary apparatus. Twenty years ago they commenced work in the dark, handicapped by a lack of knowledge of the principles they sought to apply, and under the necessity of proving each step taken. The results are, doubtless, far greater than were anticipated even by the inventor's enthusiastic imagination. What will be accomplished in the next twenty years by the engineers of to-day, who are taking up the work with a wealth of positive data in hand and unlimited capital behind them, is a question best left to individual speculation, for in the light of experience, no limit can be set to prophecy, and a serious discussion of the question is impossible.

POLYPHASE ALTERNATING CURRENTS FOR ELECTRIC RAILWAYS

By Professor Dugald C. Jackson

CARS ON THE LUGANO MULTIPHASE ELECTRIC RAILWAY IN SWITZERLAND. INSTALLED BY MESSRS. BROWN, BOVERI & CO., BADEN, SWITZERLAND

THE extension of suburban and interurban electric railway lines into district railways, and the application of electric traction to trunk-line feeders having considerable length, has sharply disclosed the need for some plan by means of which electric pressures much higher than the standard 550 volts may be used. The question of electric pressure is one which enters into economy of operation as well as into first cost in long railway lines, since increased electrical pressures give increased freedom in the selection of economical sites for generating stations, and the cost of feeder lines may be largely subordinated.

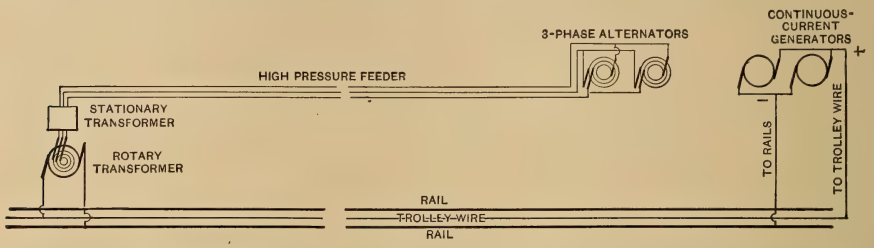
With the standard pressure of 550 volts, the feeding of a line which reaches twelve or fifteen miles away from the generating station is a matter of much concern, and numerous electric railway companies are operating auxiliary generating stations of comparatively few hundred kilowatts' capacity which are located less than ten miles from the principal stations, these auxiliary stations having been constructed solely for the purpose of feeding straggling country lines.

In some cases auxiliary stations have been built without previously exhausting the capabilities of the 550-volt continuous current for reaching out from the principal station; but, as a rule, auxiliary stations are built only after their existence becomes an imperative necessity in the opposing face of

the proved economic advantages of consolidated generating plants.

A minimum number of generating stations, each equipped with substantially constructed units of reasonably large capacity, is so clearly seen to be conducive to economy in the operating department of an electric railway, when viewed from all points of sight, that good engineering judgment can consent to the construction of auxiliary stations only under stress of necessity. Indeed, the flexibility in the transmission and distribution of power which is possessed by alternating currents gives them a very attractive advantage for use where considerable distances are to be covered; but until lately their use in electric traction has been impracticable because no satisfactory means existed for properly utilising their energy at the point of delivery,—the substation, or the car.

The difficulty due to lack of means has been so far overcome that there are now no less than three methods of greater or less advantage, depending upon local circumstances, by means of which polyphase alternating currents may be utilised in transmitting or distributing power for electric railways. These involve:—



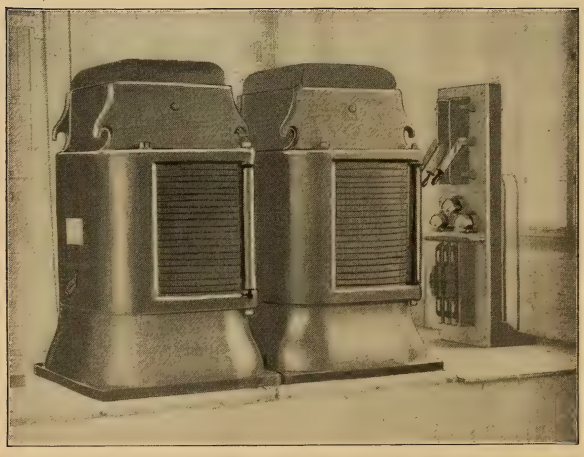
A DIAGRAM OF RAILWAY CIRCUITS WITH HIGH-TENSION FEEDERS AND ROTARY TRANSFORMERS

First. Rotary transformers in auxiliary stations driven from polyphase alternators in a centrally located principal station, a continuous-current distribution for the heaviest district immediately around the principal station being also maintained from it.

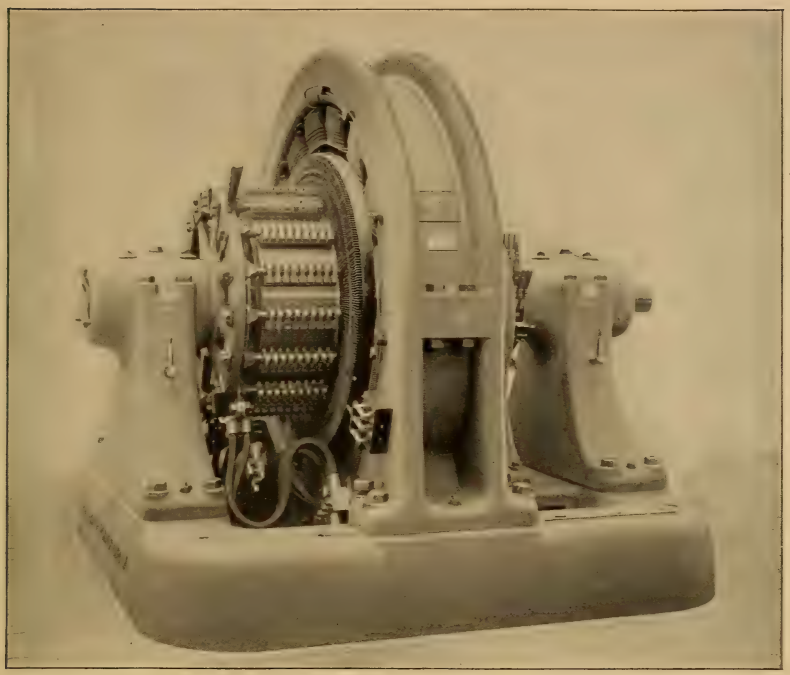
Second. Polyphase alternators driven by water or steam power at an economically located principal generating station, with rotary transformers along the line to feed standard continuous-current motors.

Third. The same arrangement of generating station as in the second method which feeds polyphase motors on the cars.

The first method may be directly grafted on existing electric railway systems, and it has been in use for several years in the United States on various railways involving extended lines. It has lately been adopted in other countries also for use in extensive tramway systems. The method is a natural resort for avoiding auxiliary steam-driven generating stations, as its adoption requires no sweeping change in the arrangement and operation of the main



STATIONARY TRANSFORMERS IN THE NIAGARA FALLS POWER STATION. CAPACITY, 350 K. W. EACH.



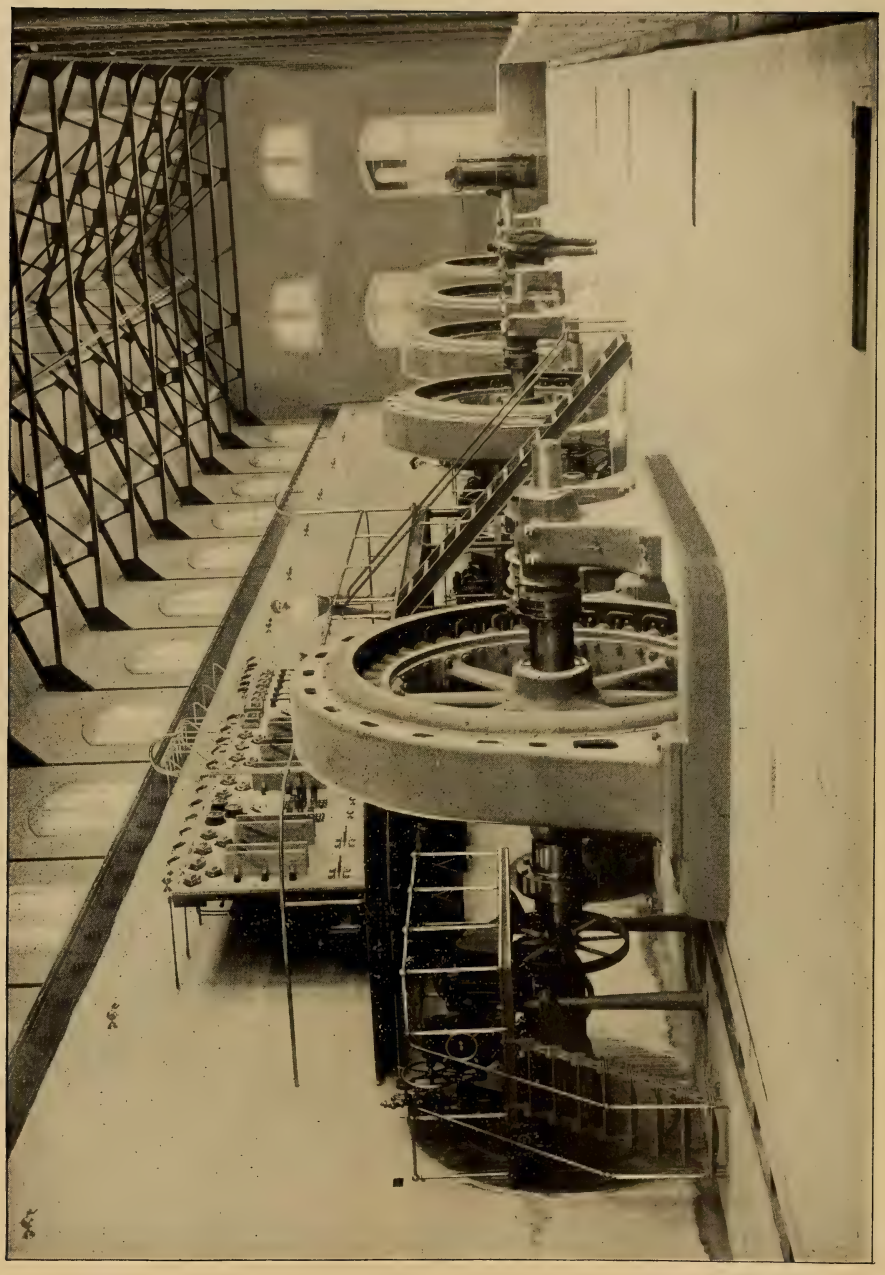
A ROTARY TRANSFORMER

power station, and no change in the construction and operation of trolley lines and motor cars.

The arrangement of the circuits is diagrammatically illustrated on the opposite page. In the power station are placed polyphase alternating-current generators of a capacity sufficient to operate the outlying lines. These supply current at a reasonably high pressure to feeders which run to the outlying sections and terminate in stationary transformers which reduce the pressure on the lines and deliver the current at reduced pressure to rotary transformers. These convert the polyphase alternating currents into continuous currents which may be delivered directly to the trolley lines. The efficiency of this double transformation is remarkably high.

The construction of stationary transformers, fairly small specimens of which may be seen hanging from electric light poles or bolted to the buildings in many places, is so well known that nothing need here be said of their characteristics; but rotary transformers are not so familiar, and knowledge of their characteristics is even less widespread. These characteristics are really very interesting, and result in a machine of much value for service in many types of electric plants in which polyphase electric currents are used. Briefly, the rotary transformer consists of a multipolar, continuous-current dynamo with its usual armature winding and commutator. On the shaft, back of the armature, are placed collecting rings, to be used for the purpose of leading the alternating currents from the feeder lines into properly chosen points in the armature winding. When the machine is running at its proper speed, the alternating currents drive it as a motor and are, at the same time, converted by the action of the armature into a continuous current, which is drawn off into the trolley circuit by means of brushes on the commutator at the front end of the armature.

This machine will run at a perfectly uniform speed, which is fixed by the "frequency" (number of oscillations per



A SET OF 12,000-VOLT REVOLVING FIELD ALTERNATORS. BUILT BY THE GENERAL ELECTRIC COMPANY, NEW YORK

second) of the alternating currents fed into it, and it transforms the alternating currents into a continuous current at a fixed ratio of pressures. It may be put into service as readily as any electric motor may be started, and, when running, it requires little attention, since the armature revolves with perfect freedom in the bearings. The efficiency and capacity of a dynamo arranged to operate as a rotary transformer are a little greater than the efficiency and capacity of the same dynamo operated either as a generator or a motor.

There is nothing more wonderful in this remarkable world of ours than the operation of a stationary transformer. The transfer of power, even in enormous quantities, from one wire to another having absolutely no mechanical or electrical connection with the first, seems completely inconceivable, but thousands of stationary transformers do exactly this inconceivable thing day after day throughout the year without attracting much notice. This transfer of power is made, in fact, in accordance with what are very simple laws, now that we have come to understand their operation, through the intervention of intangible magnetic force which links itself between the electric circuits.

Little less wonderful is the action of the rotary transformer in changing alternating currents into a continuous current of equal power through the intervention of a bit of an electric circuit called an armature which revolves in a fixed magnetic field. In this case the primary and secondary electric circuits are electrically one, each terminating in the same armature winding, but in one of them alternating currents flow, and in the other flows a continuous current. Such wonders are beyond the powers of man to originally conceive, and their existence as a portion in the economy of nature has been discovered only after laborious experiment.

In a plant belonging to the type under consideration it is necessary for the principal station to contain generators for both continuous and alternating currents, the former to furnish the power for the concentrated portion of the railway system within a reasonable radius from the power house, and the latter to furnish power for the feeders running to the outlying rotary-transformer stations. In a large plant all of the generators will be large, direct-connected machines, and, to avoid duplication of spare engines and generators, the latter might be arranged to be used in common for continuous current or alternating-current service, though such a plan has not gone through the test of experience. The arrangement requires that the armature windings be connected both to the commutator and collector rings,—a matter of small cost in itself,—and the machines so arranged can be operated either as alternators or continuous-current generators, or to supply both kinds of current at the same time. Stationary transformers would be required in connection with the alternating-current circuit for the purpose of raising the pressure, since the machine pressure could not exceed that required on the continuous-current circuit; indeed, it must be less than that on the alternating current side.

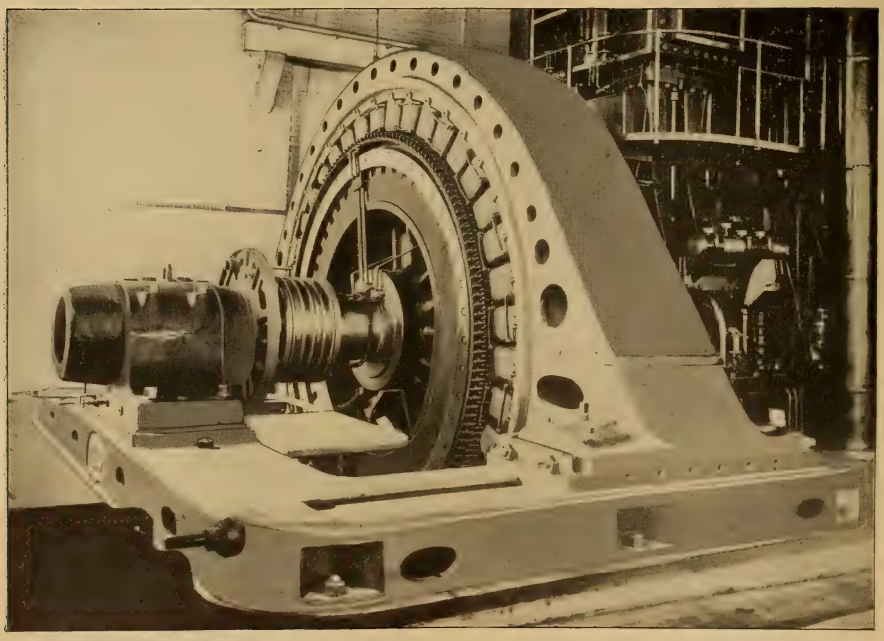
The undesirable features of such a construction spring principally from the fact that only a very low frequency of the alternating currents is obtainable from direct-driven generators of the usual continuous-current types. Frequencies of from twenty-five to sixty complete periods or oscillations of the current per second serve admirably for power transmission purposes, while to obtain the lowest of these frequencies requires a sufficient number of poles in the fields of the generator to give a product with the number of revolutions made by the armature per minute equal to 3000. A great direct-connected generator may be expected to run at a speed not exceeding one hundred revolutions per minute, as that is fully the limit of speed in large Corliss engines. To give a frequency of twenty-five periods per second, then, requires that the generators shall have thirty poles, which is too great a number to give satisfaction upon the continuous-current side, and economy will not, as a rule, allow higher speed engines to be used in very large

plants. Another alternative, reducing the frequency, is open, and this may be safely adopted if all the power in the alternating-current circuit is to be used through rotary transformers. Standard railway generators for direct connection are now constructed with from twelve to eighteen poles when designed to be driven by Corliss engines, which would give, at the limiting speed, frequencies equal to from ten to fifteen periods per second.

The aspect of the question is altered if the arrangement is based on the use of Willans engines, which give a high rotative speed coupled with high economy, a rare combination amongst the steam engines now in the market. If this engine permits us to double the speed without introducing counterbalancing disadvantages, we get frequencies of sixteen and two-thirds periods and thirteen and one-third periods per second on the alternating-current sides of generators having, respectively, ten and eight poles. The latter number is well within ordinary practice in the construction of railway generators having capacities of 300 kilowatts and upwards, and intended to run at a speed of 200 revolutions per minute.

We see, therefore, that it is entirely possible to equip the power plant with generators which may be used interchangeably as alternators or continuous-current generators, though, as a rule, there is comparatively little to be gained by such an installation, and some disadvantages are presented. Whether such a construction may or may not be adopted in the power house in no wise alters the fact that great economies may be effected by placing rotary transformers in auxiliary stations which otherwise would require engine-driven generators. Indeed, rotary transformer auxiliary or substations may often be installed with advantage under conditions which would put steam-driven auxiliary stations entirely out of the question.

In the second type of plant which has been cited, the arrangement of the machinery in the station may be simpler. The generating plant is not a *central* station, but is located solely with an eye



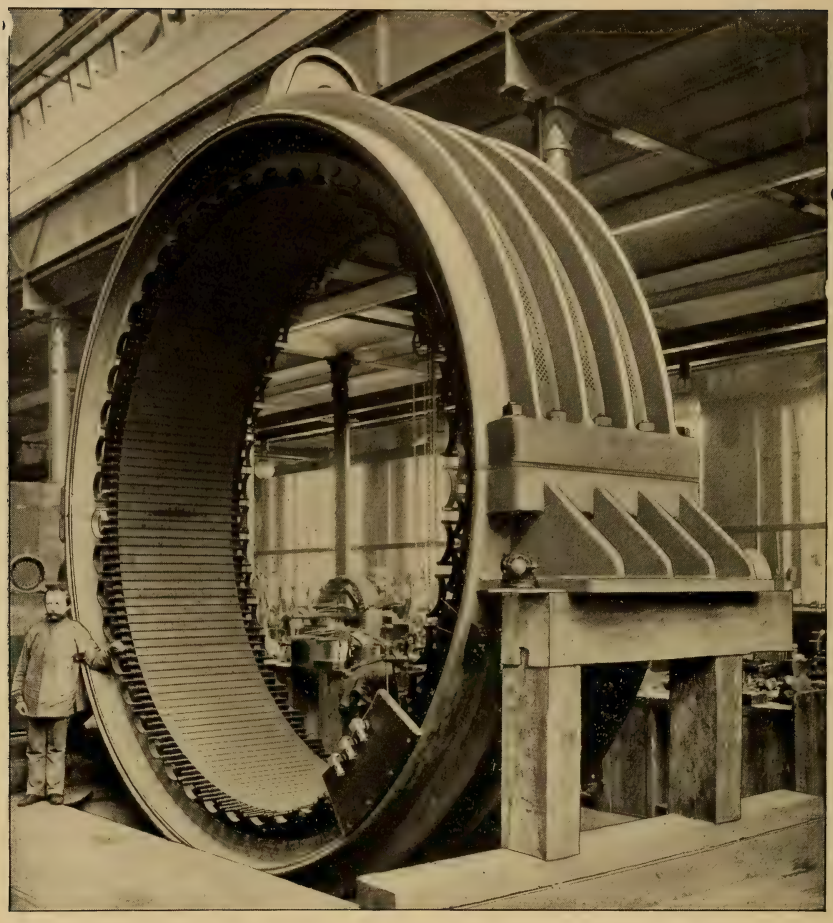
A TWO-PHASE ALTERNATOR WITH REVOLVING ARMATURE AND STATIONARY FIELDS. CAPACITY 1200 KILOWATTS. BUILT BY THE WESTINGHOUSE ELECTRIC CO., PITTSBURGH AND LONDON

POLYPHASE ELECTRIC RAILWAY AT EVIAN-LES-BAINS, FRANCE. INSTALLED BY MESSRS. GANZ & CO., BUDA-PESTH

to economy in generating electric power within a reasonable distance from the point of use. The power is all delivered to the lines in the form of polyphase alternating currents at high pressure, and these are led to suitably located rotary transformer substations for conversion into the continuous current supply to be used on the trolley lines.

The simplicity and solidity of great polyphase alternators is very well illustrated on pages 490, 492 and 495. The illustration on page 498, on the other hand, shows a continuous-current railway generator, and a comparison between the two types of generators is readily made. The illustrations make it plain that little is to be gained on the score of stability in the generating plant by a change from the usual types of continuous-current generators to standard alternators, since the former, as illustrated, have reached a high degree of mechanical and electrical excellence. Nor do we gain anything in the efficiency of generation by making the change, but we may suppress the commutator, which results in some advantage. The overwhelming advantage held, for some locations, by alternating-current generating plants lies in their capacity for generating high-pressure currents which may be readily transmitted to any reasonable distance and then transformed to any desired pressure for utilisation, or, indeed, into continuous currents.

A well-formed, but erroneous, prejudice has been in the scales against the development of means for applying alternating currents to traction, caused by the extreme inefficiency of the earlier electric lighting plants,—a condition which was brought about through ignorance on the part of the pioneer manufacturers and constructors of what



STATIONARY ARMATURE FOR A THREE-PHASE ALTERNATOR OF 1000 H. P. CAPACITY. BUILT BY MESSRS. SIEMENS & HALSKE, BERLIN AND CHICAGO

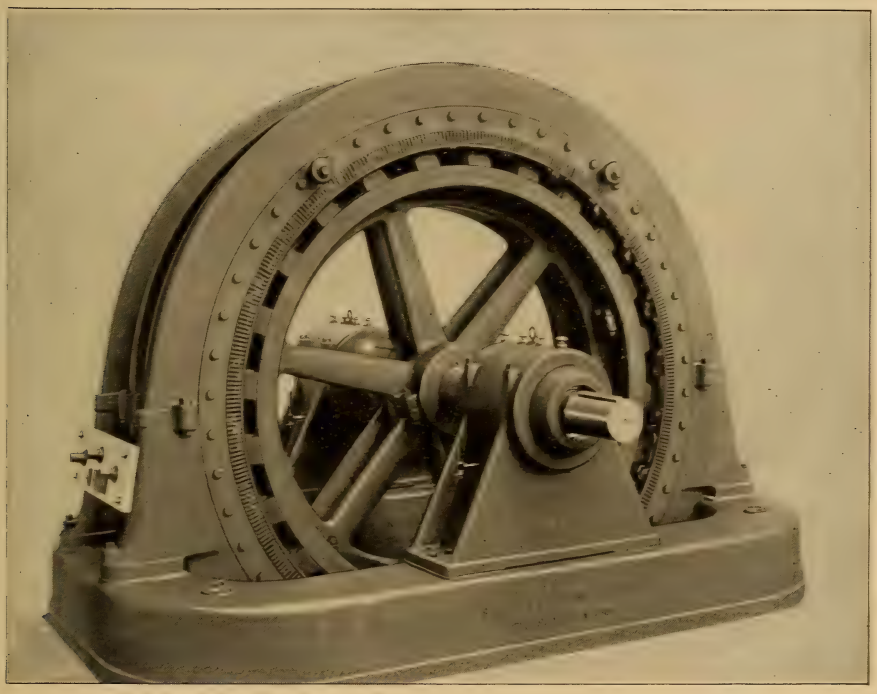
have since become known as some of the simplest and most evident of magnetic and electric phenomena. Study of alternating-current phenomena and experience with alternating-current machinery have conclusively shown that the fundamental elements, whether electrical or mechanical, which enter into the making of satisfactory and efficient electrical machinery are the same whether that machinery is to serve in a continuous-current plant, or serve a similar use in a polyphase alternating-current system.

Alternating-current phenomena are, on the whole, more generalised, and, therefore, more complex than continuous-current phenomena; but the same general laws are at the foundation of both, and the conclusions based on those laws which apply to one class of machinery can, in general, be adapted to the other class. As an illustration of the effect of rational analysis upon the construction of alternating-current machinery, it is interesting to cite the progress that has been made in stationary transformer efficiencies. Ten years ago a small transformer might reasonably be expected to present losses at full load exceeding in extent 15 per cent. of its output. At the present time a transformer of equal capacity would not be built with losses exceeding 3 or

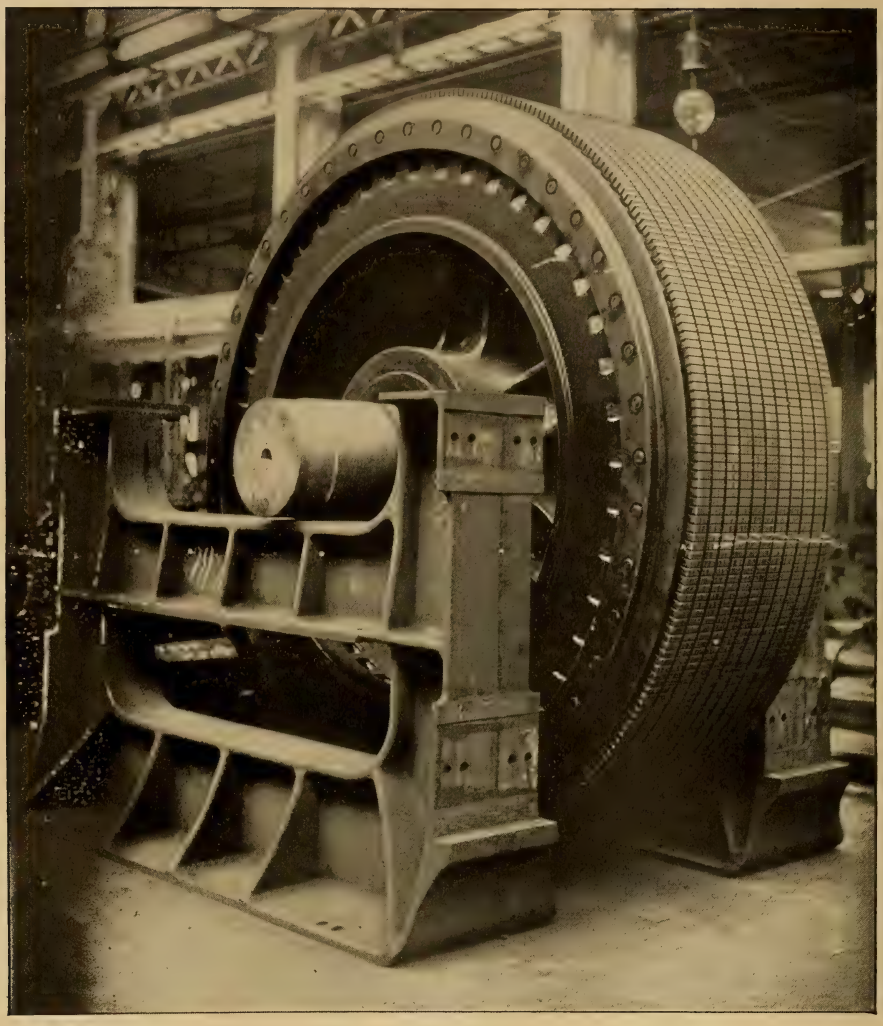
4 per cent. of its output, and machines of large size may have their losses reduced to less than 2 per cent. at full load.

This illustration fairly represents the advance in alternating-current theory and practice which has been made all along the line, and, while the limit is not yet to be seen, the period has been reached when it is clearly to be perceived that alternating currents may be advantageously admitted into a portion of the field heretofore exclusively occupied by continuous currents. In furnishing lights, power, and tramway service in the densely populated regions of great cities, continuous currents have, on the whole, apparent advantages, and as far as we can now see with clearness, will continue to hold the pre-eminent place. In regions of more scattered population, or where a cheap source of power is available at some distance from the centre of utility for the power, the alternating current may justly claim its place; hence the increasing use of alternating currents and rotary transformers in the equipment of long electric railway lines.

The rotary transformer, however great its merits, has the disadvantage, which is not shared by the stationary transformer, that it requires personal attendance. This may be discounted to a considerable extent in some projects by locating the transformer substations at fortunately situated car-houses or other points where attendance is a required feature in the operation of the rolling stock. But such embarrassment may be entirely avoided by using polyphase alternating currents directly on the cars by means of polyphase induction motors. When this arrangement is carried out, current may be transmitted from the generating station to the centres of utility at any desired pressure, and the pressure may there be reduced to any desired extent by stationary transformers which require no attend-



A 900 K. W. THREE-PHASE GENERATOR. BUILT BY THE STANLEY ELECTRIC MFG. CO., PITTSFIELD, MASS., U. S. A.



ARMATURE CORE OF A WESTINGHOUSE TWO-PHASE ALTERNATOR OF 1200 K. W. CAPACITY

ance whatsoever. The simplicity of stationary transformers is shown by the illustration on page 488 representing two large transformers in the power station at Niagara Falls, where they are used for the purpose of raising the electrical pressure for transmission to Buffalo.

An insuperable difficulty heretofore met by the plan here suggested,—the want of suitable motors,—is in a fair way to be, or even already has been, completely solved. Messrs. Brown, Boveri & Co., of Baden, Switzerland, with energy characteristic of the senior member of the firm, undertook, early in 1895, the construction of a polyphase electric-railway plant to be installed at Lugano, Switzerland. This equipment has been in commercial operation since June, 1896, and has proved remarkably satisfactory. It is a three-phase plant and requires two trolley wires, while the rails make the third conductor on the circuit. The illustration on the opening page of this article shows some of the cars on this line. Another polyphase line is in successful operation at Evian-

les-Bains, France, having been installed by Messrs. Ganz & Co., of Buda-Pesth. Of this an illustration is given on page 493.

The success attained at Lugano led to the decision of the owners of a projected railway up the Gorner Grat, in Switzerland, to equip it also with polyphase machinery. There again, as at Lugano, a water-power is available at no great distance, but a rather high transmission pressure is desirable. The Lugano generator-pressure is 5600 volts, and the frequency, 40 periods per second. The Gorner Grat Railway is a mountain line with grades as heavy as 20 per cent., and the locomotive, which is equipped with three-phase motors of 90 horse-power, works on a rack line. The illustration on page 499 shows the truck and gearing of this locomotive with one motor mounted in place.

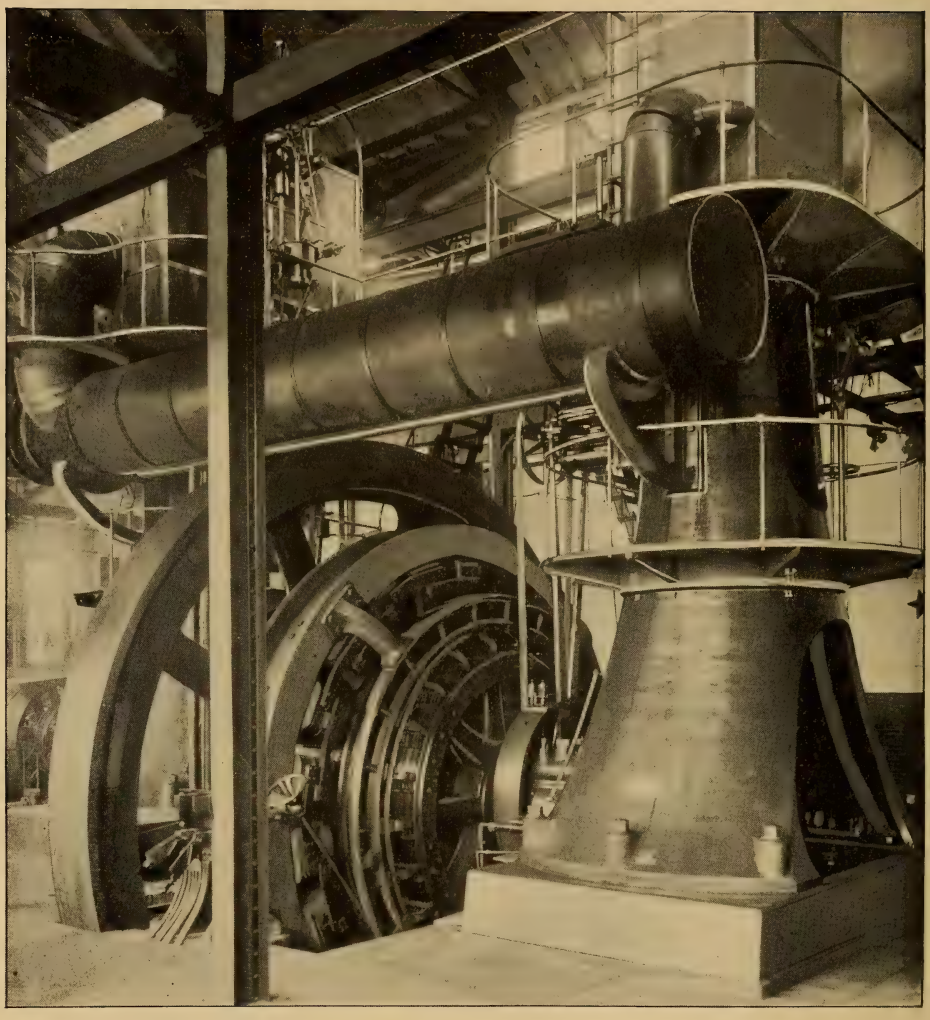
The contracts of Messrs. Brown, Boveri & Co. at Lugano and the Gorner Grat have been followed by various others, including one rack line with maximum grades of 25 per cent., and another line, twenty-five miles in length, over which the standard rolling stock of the Swiss railways is to be hauled at a speed of over twenty miles an hour by a locomotive equipped with two three-phase motors of 100 horse-power each. This firm also equipped the locomotives for the notable Jungfrau Railway.

It has been a remarkable prospect to Americans to thus see a foreign firm lead the way in the development of a branch of electric traction, even though the abundance of small water powers has made particularly favourable conditions in Switzerland. But American manufacturing companies have not been idle. The General Electric Company, of New York, for example, some time ago contracted to install a complete three-phase railway equipment at Varese, Italy. The length of the main line and branches is about twenty miles, and a speed is to be maintained on the main line of twenty-two miles an hour over grades of 4½ per cent. and with a train weighing about thirty tons. The motor cars are to be equipped with two induction motors of 75 horse-power each. Here, again, the generators are to be driven by water power, and the generator pressure is 6000 volts at a frequency of forty-five periods per second, while the motor pressure, reduced from the feeders by stationary transformers, is 550 volts.

There are certain features of alternating-current induction motors (polyphase) which cannot be readily dupli-

A FIELD RING OF A WESTINGHOUSE GENERATOR WITH BOBBINS AND BRUSH HOLDERS IN PLACE

cated in practical forms of continuous-current railway motors. These features are both advantageous and disadvantageous, but for the working of long lines the advantages are surely and heavily in the preponderance. Induction motors have the same tendency which is notable in shunt-wound continuous-current motors, to run at a fixed speed which is reasonably independent of the load, while, on the other hand, the torque and speed may be controlled



A DIRECT-CURRENT RAILWAY GENERATOR, 550 VOLTS. BUILT BY THE GENERAL ELECTRIC COMPANY, NEW YORK

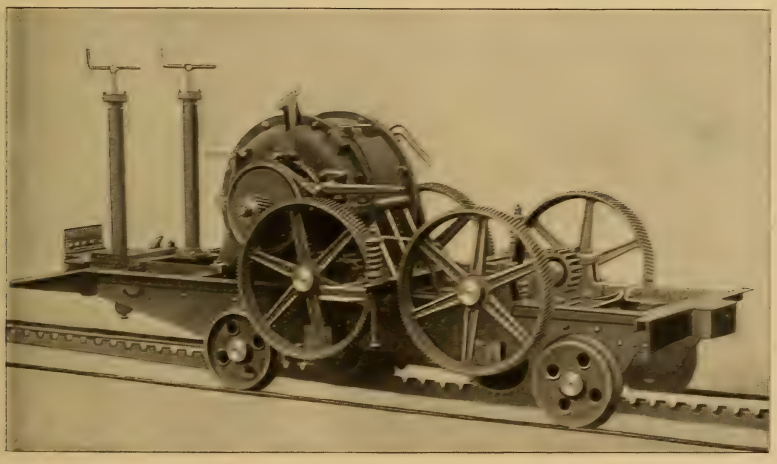
by resistances inserted in the armature circuits, or by more economical means under some conditions, so that induction motors (though inherently tending towards a reasonably fixed speed) may be made to perform in a manner which is entirely analogous to the well known and satisfactory performance of the common series-wound street-car motors. By connecting the motors in tandem, as has been developed by Messrs. Siemens & Halske, in Germany, for elevator service, and by Mr. C. P. Steinmetz, in the United States, for railway service, the torque per ampère developed by the motors on a car may be increased in proportion to the number of motors. The operation under these conditions becomes analogous to a series-parallel control of continuous-current railway motors.

A marked and valuable feature of induction motors is their action in holding back, by returning energy to the feeders, when they are driven above speed by a car running down hill. This action is entirely different from any that may be simply gained in series-

wound continuous-current motors, but is analogous to the performance which would be shown by shunt-wound motors under similar conditions if they could be satisfactorily adapted to the requirements of electric traction. The action is very simple, and is a safeguard which cannot be overestimated for cars operated over heavy grades.

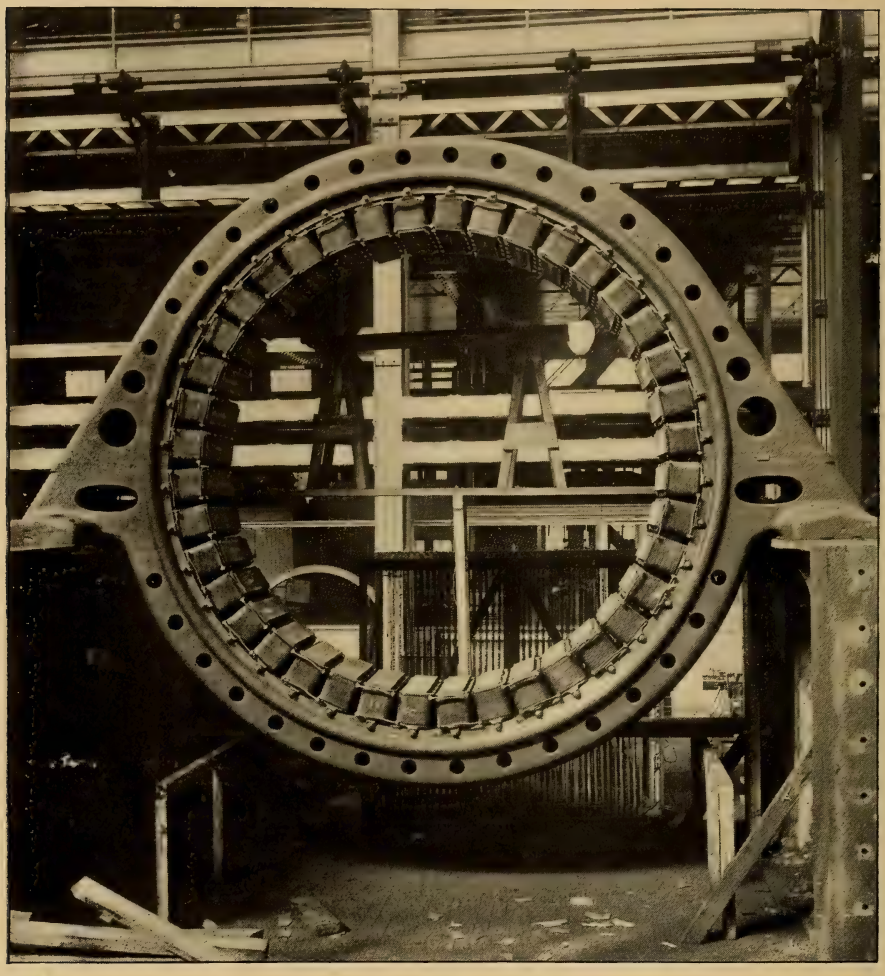
We will suppose a car approaches a dip in grade with the motors working. Upon entering the grade, it is natural for the speed of the car to increase, which, with continuous-current, series-wound motors, will continue until the speed quickly becomes dangerous unless the motors are cut off and the brakes applied. A failure in brakes under these conditions has often resulted in frightful accidents. Not so with induction motors! As the car increases in speed the forward rotary effort of the motors decreases and gradually and smoothly changes into a retarding effort, while the power given up by the car as it coasts down hill is automatically returned by the motors to the line. Thus the power of the descending car is automatically placed where it may be usefully applied in operating other cars, instead of being frittered away in wasteful and injurious friction between brake-shoes and wheels

All this is done by inherent action in the motors themselves and is entirely independent of fallible humanity, represented by the motorman. The machines may be readily so constructed that they will develop a retarding force equal to several times their normal working torque before the speed has increased by a one-third margin over the normal speed when running free on a level. Even greater advantage may be taken of this remarkable property when the cars carry two motors each, as is the usual custom in tramway service, as the two motors in tandem connection will begin to return power to the line at about one-half the normal free running speed. Stops may be made on a grade in the usual manner by cutting off the motors and applying the brakes, and starting is accomplished by the ordinary process, after which the motors may again be left to care for themselves.



LOCOMOTIVE TRUCK AND GEARING FOR THE GORNER GRAT MOUNTAIN RAILWAY IN SWITZERLAND. ONE OF THE MOTORS IS SHOWN IN PLACE

This convenient property, which is so remarkably developed in the induction motor, has been lately utilised by the writer in a factory power distribution plant. The industry was one demanding much elevator service in various buildings from four to six stories high and with the heavy preponderance of load on the down trips. The use of



FIELDS FOR A 1200 K. W. TWO-PHASE ALTERNATOR. BUILT BY THE WESTINGHOUSE ELECTRIC COMPANY, PITTSBURGH AND LONDON

induction motors attached to efficient winding gear enables efficient hoisting to be attained, while the holding back power of the motors after the load is started, is relied upon to safely lower the heavy down-loads. The preponderant down-loads are thus made to deliver up to the electrical system their energy of position, so that it may be appropriated to useful work by other machines. The entire operation is independent of the elevator man, who simply starts the motor when he desires to move, and stops it by opening the switch and applying the brake when he desires to stop. The operation becomes efficiency and simplicity itself and may be performed by any factory hand who has occasion to move a load between floors.

There is a curious tendency of the alternating current to forsake the centre of a conductor and flow only through the parts of the conductor near the surface. This " skin effect " is caused by the magnetic reversals which are set up by the alternations of the current, and it results in an increased resistance to the flow of an alternating current through the conductor, as compared

with the true resistance opposed to the flow of a continuous current. The magnitude of the effect depends on the frequency of magnetic reversals, the thickness of the conductor, and the material of which the conductor is composed.

In magnetic materials, such as iron and steel, this "skin effect" is greatly increased, and experiments of the writer show that the "consequent resistance" of an 80-pound tee rail of Bessemer steel may, when the frequency of the alternating current is twenty-five periods per second, be as great as four times the true electrical resistance which the same rail offers as a path for continuous currents. When the alternating current has a greater frequency than twenty-five periods per second the "consequent resistance" is still further increased. This tendency, however, is not likely to be a serious matter in polyphase railway plants, as the skin effect does not make itself appreciably felt in non-magnetic copper wires of ordinary thickness, and in the construction of a trolley line stationary transformers can be, and ordinarily should be, placed at sufficiently frequent intervals along the line so that heavy secondary feeders are not required to reinforce the conductivity of the trolley wires. The rails, which constitute the third branch of the polyphase circuit, are of many times as great cross-section as the trolley wire, and, hence, when properly bonded, are likely to have fully as great a conductivity as the trolley wires notwithstanding the "skin effect."

It is interesting to note that polyphase alternating-current railway plant, properly installed, removes much of the difficulty from electrolysis of water pipes and other underground metallic structures, notwithstanding the use of the rails for one branch of the circuit; but, on the other hand, in the line construction are involved all the difficulties of the double trolley.

What the ultimate development in electric traction will be it is impossible to say, but it is clear that polyphase currents will play an increasing part in it, and on fairly long lines with a limited traffic, and on lines with heavy grades, polyphase motors will play an important part. An especially strong part is to be played by polyphase currents in electric traction where cheaply developed water power is available at a reasonable distance from a railway line.

THE SELECTION OF ROLLING STOCK

By C. F. Uebelacker

THE selection of suitable rolling stock for street railway use has but recently acquired the dignity of being considered as a problem by itself. In the bygone days of horse-railroading there was practically no selection. The use of one horse or two horses per car settled the question of size and weight, and the only remaining questions were those of colour, finish, and builder.

With the introduction of mechanical power and the consequent enormous increase in territory and possibilities, came a corresponding increase in types and details in the means of transportation. The requirements of service became widely varied, and still more the means of meeting them.

The interurban line, with but small patronage to depend upon in the district lying between the towns which it connects, needs not run cars very frequently. The distance over which it carries the larger number of its patrons is too great to be covered by walking; it is, in fact, generally greater than could be covered by driving before being overtaken by the fast-moving car, and time is really saved by waiting fifteen or twenty minutes for a car instead of starting at once by other means. If the road be a paying one, each car must carry a good load, as there is a large investment in track and line upon which dividends are to be earned with infrequent service. In order to meet these conditions satisfactorily, the car must be large,—not only large enough to carry, but also to seat, the ordinary load. People do not enjoy hanging by a strap for an hour at a time, and if the journey be unpleasant, it will not be repeated more often than can be avoided. Cars for such service must be fast, well heated, well ventilated, and well lighted. Provision must be made for smokers, and frequently for express service and mail also.

Let us assume, as an example, that a line of the general character under consideration is ten miles long! The track, roadbed, right of way privileges, and overhead line have cost, say, $100,000, or about £20,000. No serious competition existing, it has been decided that half-hourly service is sufficient for ordinary occasions. Take fifteen miles per hour as the average speed from end to end of line, allowing for slow speed and numerous stops in the towns, and greater speed and fewer stops in the intervening space! It will require, under these conditions, four or five cars to cover the road and provide for special occasions. These, with the necessary generating plant and car sheds, would add about $25,000, or, say, £5000, more to the investment account.

The headway assumed would probably make a schedule mileage of about 700 miles daily. Twelve cents,—sixpence,—a car-mile would be a fair figure for operating expenses under such conditions, which, added to 6 per cent. interest on bonds, 5 per cent. depreciation, and 10 per cent. dividends, extensions, surplus, etc., would make up a daily charge of about $116, or £23.4.0, to be met by the average daily earnings. Assuming that revenue

from express service and the carriage of mails will cover $10 (£2) of this, we must still carry about 1100 passengers daily at 10 cents (5d.) per fare to meet the charges. This would mean an average load of 14 or 15; but as an average load is the exception, at least double this seating capacity should be provided.

In wide, cross-seat, closed cars, about 24 feet in length would provide this capacity. Add to this about 6 feet for freight space and 10 feet for platforms and vestibules, and we conclude that a car, about forty feet over all, would be required for service of this nature.

Let us turn now to city work, which is the other extreme from what we have just been considering as regards conditions. Here the headway must be short. Many passengers ride a few blocks only, and if a car is not in sight they will walk. During most of that portion of the day when the streets are most frequented, the headway must be kept much shorter than the seating capacity of the cars requires. Then come the rush hours, when people are going to, or leaving, business, and again, later, care must be taken of the theatre crowds.

The maximum headway for the greater portion of the day is pretty well fixed by the condition mentioned above, while the minimum headway is a question of the size of the crowd to be carried and the capacity of the individual cars. Two other points bear pertinently upon the question of the most desirable car for this service.

One is the cost of power. A large, heavy car will, of course, carry more passengers and will not require a larger crew than the smaller one. On the other hand, the maximum headway is fixed independently of the capacity of the car, and these large cars mean large coal bills for the power house. It is not the power required to keep them in motion which counts up, but that required to start and accelerate them.

The second point is that bugbear of every railroad manager, the extra list, and the short-day men. A large extra list is for every reason undesirable, but it is a necessary evil on city lines where as many passengers must be carried between 5 and 6.30 P. M. as from 9 A. M. to 5 P. M. To meet these daily rushes, extra cars must be crowded into service, for, at the most, two or three hours in the morning and at night, and these cars are handled by men who receive pay only for the few hours during which they work.

The result is a body of employees thoroughly dissatisfied and careless in the performance of their duties. They do not regard their positions as sufficiently desirable to be worth much effort. The smaller this extra list can be kept, the quicker the new employee passes through it to the "full-day runs," and the more attractive does the good pay and steady work of railroading become to the class of men who make desirable employees. In this respect the large car is decidedly preferable, inasmuch as, the greater the capacity of each car, the fewer become the extras that are required during rush hours.

Probably the best solution for strictly city work, with its frequent stops, lies in the mean between large and small cars, such as are now being put on the Metropolitan Street Railway Company's lines in the city of New York. These have 22-foot bodies, with side seats, double doors, large platforms, and no vestibules. Although carried on four wheels, they are well supported for nearly their entire length by the truck framing, and, consequently, do not have to be constructed so heavily, in proportion to their size, as do bodies for double-truck service. They are light to handle in the quick stops and starts required in city service, and passengers can leave and enter them quickly, even when crowded.

In this last respect there is more difference than is generally realised. In the course of some experiments made by the writer a short time ago, he noted and compared the average service stop of several different styles of car running over the same line. The average of the 18-foot box car, with trailer at-

tached, was 7 seconds, while that of a 28-foot car of similar internal arrangement was 9 seconds. As these cars made over sixty stops in the four-mile run over which they were operating, the 18-foot car and trailer gained two minutes on each half trip over the longer one. This, however, should not be taken as an argument for the use of trailer cars. Their few advantages are offset by a host of objections. They have been the cause of many accidents and of more earnest profanity than the very mules which used to haul them before the days of the electric motor.

During the past few years the so-called open, or summer, car has come into great prominence. That these cars are favourites with the public, and, consequently, increase the receipts during the time they are in service, needs no better proof than the willingness of so many corporations to purchase and maintain double equipments of rolling stock. The problem of producing a car that will exhibit the desirable features of the open car and at the same time provide the protection needed in cold weather has received a good deal of thought. No altogether satisfactory solution has, however, yet been made public.

Of the good points which render the open car such a favourite there are several. It has large seating capacity, and there is less likelihood of one passenger being crowded by another standing in front. The free circulation of air renders smoking on the rear seats unobjectionable. It is easy of access; passengers seated are less often disturbed by others entering or leaving. The seats are arranged transversely, and riding thus, with the feet braced against the foot-rest in front, and the shoulders against the back of the seat, it is much easier to steady one's self against the jar that occurs on starting and stopping. Above all, the coolest place to be found, on a warm day, is on the shady side of an open car in motion.

The weak points of the open car are mainly structural. The roof must be as firm and heavy as in the box car; but the posts lack the support given by the panels, which must be left out to permit access from the sides. The absence of the panel also leaves the long side sills to be supported without the aid of the truss usually embodied in the design of box cars. This last is of small moment, however, when the cars are to be used on four-wheel trucks, as with these the spring base is now very long and additional extensions are provided, which form a truss for supporting the overhanging ends of the sills from underneath. The greatest objection is the height of the step from the ground to the run-board. This frequently reaches 20 inches, and it requires a fairly active person to comfortably ascend or descend 20 inches at a single stride.

The space required by the motors practically limits the minimum diameter of the wheels to 30 inches. The car floor, to ride clear of the motors, must be about 32 inches above the rail, and this distance must be covered in two steps, one from pavement to run-board and one from run-board to car floor. An additional step is generally impracticable, on account of the great width between tracks necessary for cars so equipped to pass. With cars accessible by means of platforms at the ends, this difficulty is met by leaving a reasonable step between the car floor and that of the platform; but access via the platform means an aisle down the centre or side of the car, which reduces the seating capacity seriously, and is not as convenient or rapid a means of access as the run-board. With the present designs we must, on the one hand, accept the inconvenience of a high step and a car which not only is impossible to heat, but is totally unfit for inclement weather of any kind, or we must cut down the seating capacity at least one-fifth and put up with long delays at each stop.

Car heating and lighting are both questions which deserve considerable attention, but which they frequently do not receive. Comfortable accommodations are always a paying investment in street railroading. The question of heating generally turns on the choice between electrical heaters and coal

stoves. Here and there will be found cars equipped with hot-water heaters, but they are not numerous. The first cost is too high to bring them into general favour.

There cannot be much question as to the relative economy of the two first-mentioned methods of heating. It is certain, to start with, that the energy of coal cannot be turned, first, into mechanical power, then into electrical, transferred through several miles of wire and then reconverted into heat, as economically as heat can be obtained from the direct consumption of coal at the point where it is required. This is true even when all the incidental expenses of installing and removing stoves, handling ashes, laying and cleaning fires, and kindling are taken into account.

On the supposition that electrical energy costs but three-fourths of a cent per kilowatt-hour, and an average of six ampères of current is sufficient to provide the necessary heat, it costs about 2½ cents an hour to warm a car, while records kept by the writer for several months showed the average cost for heating with stoves to be only about 0.9 cent per hour per car, or, on the mileage basis on which the records were kept 0.11 cent per car-mile. Some small stoves ran as much as 20 per cent. less, but failed to furnish an appreciable amount of heat.

The great objection to the stove is that it heats the space near it to an uncomfortable degree, while the more distant places, especially at the forward end, remain cold. Cars should not be kept too warm, especially in city service, as people seldom remove wraps on entering, and any temperature above 50° or 55° F. becomes oppressive.

The heat due to the presence of people in the car alone reaches an appreciable amount. Experiments by the writer showed a difference of from 15° to 25° F. between the temperature inside and outside of a loaded car in service with no heating apparatus in operation. On the whole, it is perfectly safe for ordinary temperate climates to supply heating apparatus capable of raising the temperature of the empty car in motion 35° F. Even if the external temperature fall to 0° F, this will give 50° or 55° F. inside a loaded car, and this is ample for comfort.

Despite its inferior economy, the electric heater has many advantages which are rapidly making it a general favourite with both managers and the riding public. It is cleanly; there are no ashes or coal littered about the car; it does not take up any seating capacity; the heat is distributed over all parts of the car, and the warm air sweeping over the floor keeps it dry, as no stove can. The heaters need not be removed each spring and replaced each fall. They are always in place, ready to be put in service in case of a chilly evening, or any unseasonable weather.

They require, however, rather more current than was assumed above. To heat an 18 or 20-foot closed car 30° F. takes at least 9 ampères, while a 25-foot body will take from 12 to 14 ampères for the same rise in temperature. Roughly speaking, it requires about three watts, or, at 500 volts, 0.006 ampère per cubic foot of car space. However, electric heaters are more comfortable as well as more expensive than stoves.

Lighting is another point that is generally left to the builder and receives little consideration from the manager. The result is that five or ten lamps are wired in a row along the centre of the ceiling. This row is broken by one or two clusters, more or less ornamental, and the scheme of lighting is complete. Yet, for a car having longitudinal side seats, no more incomplete arrangement could be devised. The main body of lamps should be placed along each side, where they will furnish more available light and add to the effect of the interior decoration.

The frequent failure of power on the line, due to the opening of the safety devices at the power house, induces many roads to use oil headlights, and even to equip the cars with one or two oil lamps to prevent entire darkness when the incandescents go out. When a large number of cars are run on the

same circuit and overloads are frequent, this is quite a necessary precaution; but on interurban roads, when the headways are long, it is scarcely necessary.

We have looked at the questions so far considered mainly from the traffic manager's point of view. While this is not the only side of the question, it is certainly the most important one, and, as such, has been first taken up. That part of the operating expenses, namely, wages to trainmen, which falls directly under his supervision, is probably 30 or 40 per cent. of the whole, so that a small percentage of saving in this item counterbalances a comparatively large increase in others. Power, for instance, represents only from 6 to 8 per cent. of the operating expenses. If the use of large, heavy cars cuts off a run or two, the extra expense for power cuts a small figure in the result.

Passing to the engineer's point of view, one of the first difficulties we come in contact with is that of width of cars. With the sharp curves necessitated by turning corners in narrow city streets, double trucks assume a very considerable angle with each other and with the car body carried by them. These trucks must have a length of wheel base sufficient to accommodate the motors between the bolster and the axle at each end, or, the wheel base must be equal to the width of the bolster, plus twice the space taken up by the motor and its supporting bars.

In order to gain access to the car with but one step between the platform and the ground, it is essential that the wheels should swing between the car sills, *i. e.*, that the sills shall be dropped down outside of them about 4 or 5 inches. This being the case, the sills must have sufficient space between them to accommodate the extreme angular position assumed by the trucks in swinging around the sharpest curve. The longer the car, the worse this condition becomes, as the increased length of body necessitates increased separation of the trucks, and the chord of the curve subtended, being greater, the angle they assume with the body increases. It then becomes evident that, in narrow city streets with sharp curves, progress in lengthening the car body soon is barred by the narrowness of the space allowable between tracks.

With the single trucks, the limitation is the practicability of handling long wheel bases on sharp curves, and the length of body which can be carried steadily on such wheel bases. A few years ago general practice in the United States, as is the case in Europe now, was to restrict the wheel base to 6 feet at the most, while now, after a few years' experience, a 7-foot wheel base is used almost universally in the United States, and in many cases it measures 7½ and 8 feet.

With recent improvements in single trucks, there is no difficulty in carrying heavy 24-foot closed bodies on a 7-foot wheel base at such moderate speeds as 15 or 20 miles an hour. They ride with perfect steadiness and a smoothness that leaves little to be desired. On the other hand, a 7-foot wheel base will, with a properly designed flange, round a 30-foot mean radius curve without any undue expenditure of power and with no danger of derailment.

There is at all times the argument of economy in favour of single trucks. On large roads where the repair forces at the various car sheds are assigned in proportion to the number of cars to be maintained, each double-truck car is always considered equivalent to 1½ single trucks, and the men are assigned on this basis. The repair accounts also show a corresponding difference in favour of the single trucks.

Certain conditions, undoubtedly, can be met only by cars so large that double trucks are necessary to properly carry them. Such, for instance, is the case assumed at the beginning of the article. Even in purely city service there are cases where the double trucks and long cars can be used to advantage. Yet, where 24-foot bodies, or smaller ones, meet all requirements, the single trucks are the cheapest, both in first cost and maintenance.

STORAGE BATTERIES AND ELECTRIC RAILWAYS

By Herbert Lloyd

UNTIL very recently it has been the impression, even among engineers, that the only field for the storage battery in connection with electric railways was in what might be called the storage battery system pure and simple, that is, a system in which the batteries propelling the car were carried upon it. While recent improvements in the manufacture of battery plates have brought this method of propulsion again to the front, it will not be discussed in the present paper.

Within the past few years a new field, and one which promises to be one of great magnitude, has been opened for the use of storage batteries. This is the installation of storage batteries of large size to act as regulators in connection with the trolley or third-rail system of propulsion. A battery to be suitable for this class of work must be capable of charging and discharging at very high rates with comparatively small changes in voltage, and in order to accomplish this the battery must be essentially of low internal resistance, and, consequently, must have a very highly developed plate surface.

Fig. 2 is a set of diagrams taken from a series of cells having a capacity of 500 ampères for one hour, and is intended to show the difference in voltage between a charge of 500 ampères and a discharge of 500 ampères. The first series of diagrams shows charges and discharges of five seconds' duration, at 500 ampère rates; the second series is of ten seconds' duration; and the third series, of thirty seconds' duration. The first set of diagrams on the left shows the difference in voltage with the battery completely charged, the next after a discharge of fifty ampères, and so on, until 450 ampère-hours have been taken from the battery. The bottom diagram shows the percentage of fluctuation at all conditions of charge from the battery full to the battery discharged down to 90 per cent. of its one-hour capacity. The regulation is poor when the battery is completely charged, but from 10 per cent. discharge down to 90 per cent. the maximum fluctuations are approximately 10 per cent.

Such batteries are now being made and installed on a large scale on some of the largest street railway systems in the United States. About 250 cells are usually installed, some of them weighing as much as a ton each. Heavy wooden tanks, lined with sheet lead, are used as containing cells, and the plates are welded together throughout the entire battery to insure the lowest internal resistance as well as the most durable form of construction.

A reliable battery, properly installed, will reduce the problem of generation and distribution of electric current by a street railway system to the simple question of handling an even, steady, predetermined load. Installed in the power house, it will allow the use of a smaller number of the most highly efficient generating units, which, being operated for long periods, fully and steadily loaded, will reduce the cost of power generation to one-half of what is possible with the apparatus best suited to the variable demands made upon most railway power houses.

A battery will take the place of all that generating machinery which is

FIG. 1.—A STORAGE BATTERY PLANT INSTALLED BY MESSRS. MATHER & PLATT, LTD., MANCHESTER, ENGLAND, FOR THE DOUGLAS & LAXEY COAST ELECTRIC TRAMWAY ON THE ISLE OF MAN

made necessary by the loads in excess of the average output. It will act absolutely instantaneously in regulating a violently fluctuating load. It is more economical to install for a continuous output of energy than a generating unit that will not have at least a full, steady load for three hours at a time, and it has the great advantage over generating machinery for such loads that, instead of sharing with the rest of the plant a fluctuating load, it is a source of additional output that, in itself, takes care of all such fluctuations and violent changes, leaving the rest of the plant changes. The same reasons apply also to the increase in size and reduction in number of generating units, as a battery, having half the output of a unit, can keep it fully loaded by discharging on the first half of the increase of load and charging on the last half, at the beginning of which the machine would be thrown in. The number of running hours of the station can be materially reduced, as the night load is usually so light, for four or five hours, that it can be taken care of entirely by the battery.

A battery is also an admirable protection against fly-wheel accidents. For

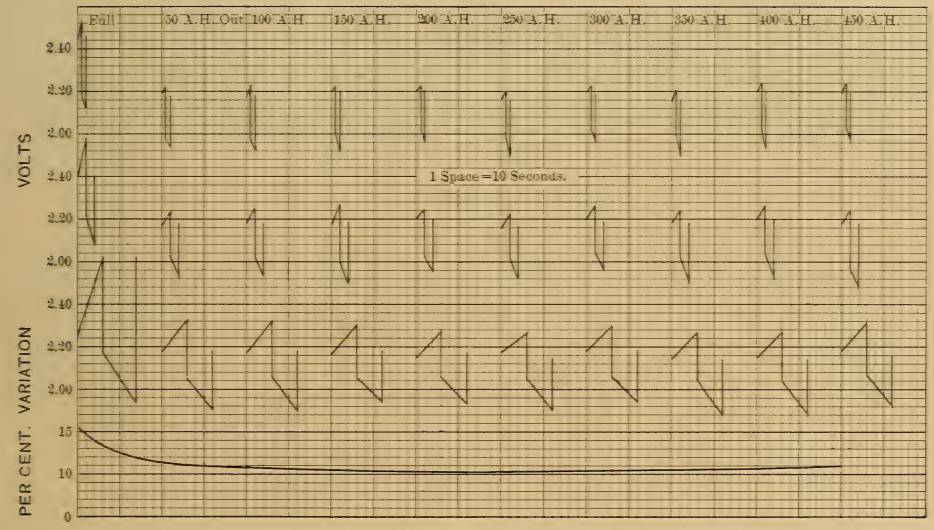


FIG. 2.—DIAGRAM SHOWING DIFFERENCE IN VOLTAGE BETWEEN A CHARGE OF 500 AMPÈRES AND A DISCHARGE OF 500 AMPÈRES

fully and steadily loaded and allowing the use of a class of machinery of much higher economy than is otherwise possible. A battery further reduces the number of times a unit has to be started and stopped to follow the load line, as with a steadily increasing load coming on the station, the battery, by discharging, can take care of it until it reaches such an extent that an additional machine can be put in service fully loaded, filling the battery again until the output increases to the capacity of the machine.

The battery, whether gaining or losing in the amount of energy stored, will still regulate for the instantaneous load instance, in case of a short-circuit on the line the increase in current will be taken by the battery, and when the circuit breaker goes out, the battery will keep practically the full load on the generators. When the circuit breaker is thrown in again, the high load for the first few minutes, due to the cars starting up, will be taken care of by the battery, so that the machines will go on undisturbed even under such conditions.

Although a storage battery is not in itself a generator of electricity and cannot give out what has not previously been put into it, and so cannot reduce the actual energy output of a station, it

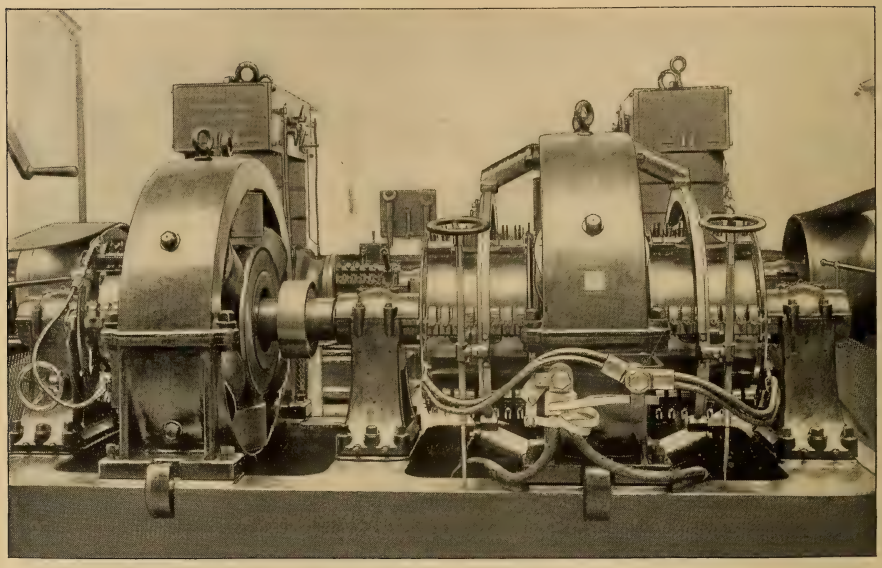


FIG. 3.—A "BOOSTER" IN THE POWER HOUSE OF THE BUFFALO STREET RAILWAY COMPANY, BUFFALO, N. Y. U. S. A.

does reduce the amount of generating machinery required, and effects a very great economy, both in fuel and labour, by keeping the apparatus installed running fully loaded and only under the most efficient conditions.

For regulating work, a battery is installed so that the difference between average and maximum load during any hour of the day shall be discharged by the battery at its hour rate; that is to say, it will give this amount of current continuously for one hour, and in emergencies it can, of course, be worked at a considerably higher rate. Under such conditions of short and sudden change and discharges of a battery there is a change of voltage of about five per cent. for its maximum rate.

If there is no objection to this change of voltage in the power house,—that is to say, from 525 volts at heavy load to 575 volts at light load,—the battery can be connected directly in parallel with the generators, provided that the series field is shunted sufficiently to under-compound the machine so that it will drop more in voltage for a given increased load than the battery does. If shunting the series field to this extent lessens the excitation to a point where the voltage is too low, about two cells of battery are placed in parallel with the series field of the machine. These cells prevent any change in current which takes place in the armature from passing through the field, and gives the effect of an independent field, in addition to the shunt field of the generator.

The potential of the small battery should be equal to the drop across the series field under conditions of the average load on the generators; under such conditions the battery will receive as much charge as it discharges, and will require no attention.

Where it is desirable that the station voltage should not fall under increasing load, but, on the contrary, increase, as in the case of over-compounded machines, a differentially wound booster should be used to over-compound the battery. Fig. 3 shows such a machine, and battery outfits operated upon this plan are in use in quite a number of stations.

The upper diagram in Fig. 4 shows the voltage of an existing station, before the installation of the battery, and

the lower diagram shows the voltage under similar conditions after the installation of the battery. The upper diagram in Fig. 5 shows the variation in load of a machine before the installation of the

FIG. 4.—VOLTAGE CURVES IN A STATION BEFORE AND AFTER INSTALLING STORAGE BATTERIES

battery and the lower one the load of the same machine after the installation of the battery. In the first instance, the variation was as much as 270 ampères, and the greatest fluctuation

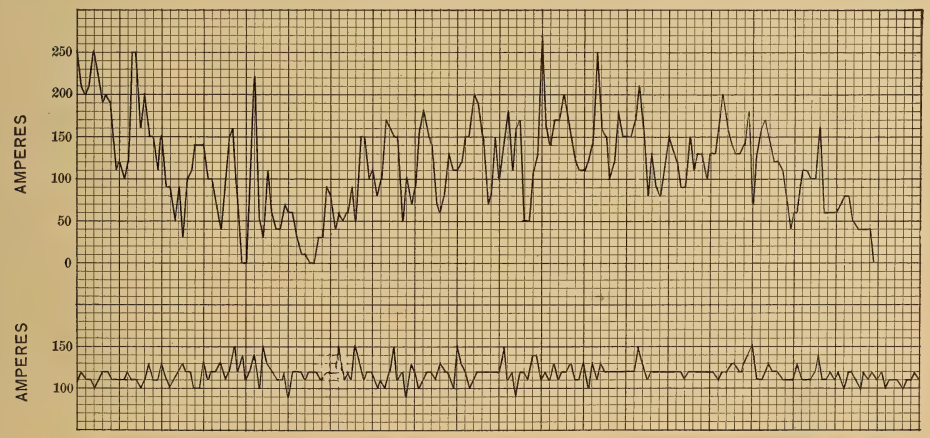


FIG. 5.—LOAD VARIATIONS BEFORE AND AFTER STORAGE BATTERY USE

in the lower one is about 50 ampères. This is a water-power plant, where the water supply is sufficient only for the average load, the battery having replaced an auxiliary steam plant and

effected a saving on a small road in fuel alone of approximately $8000 (£1600) a year.

Batteries in substations affect the problem of transmission and distribution to exactly the same extent that power houses situated at such points would, but they have the great advantage over a power house that they can be located at the most desirable point for distribution, as they occupy very little space and require neither water nor fuel for their operation.

One of the most interesting and important storage battery installations

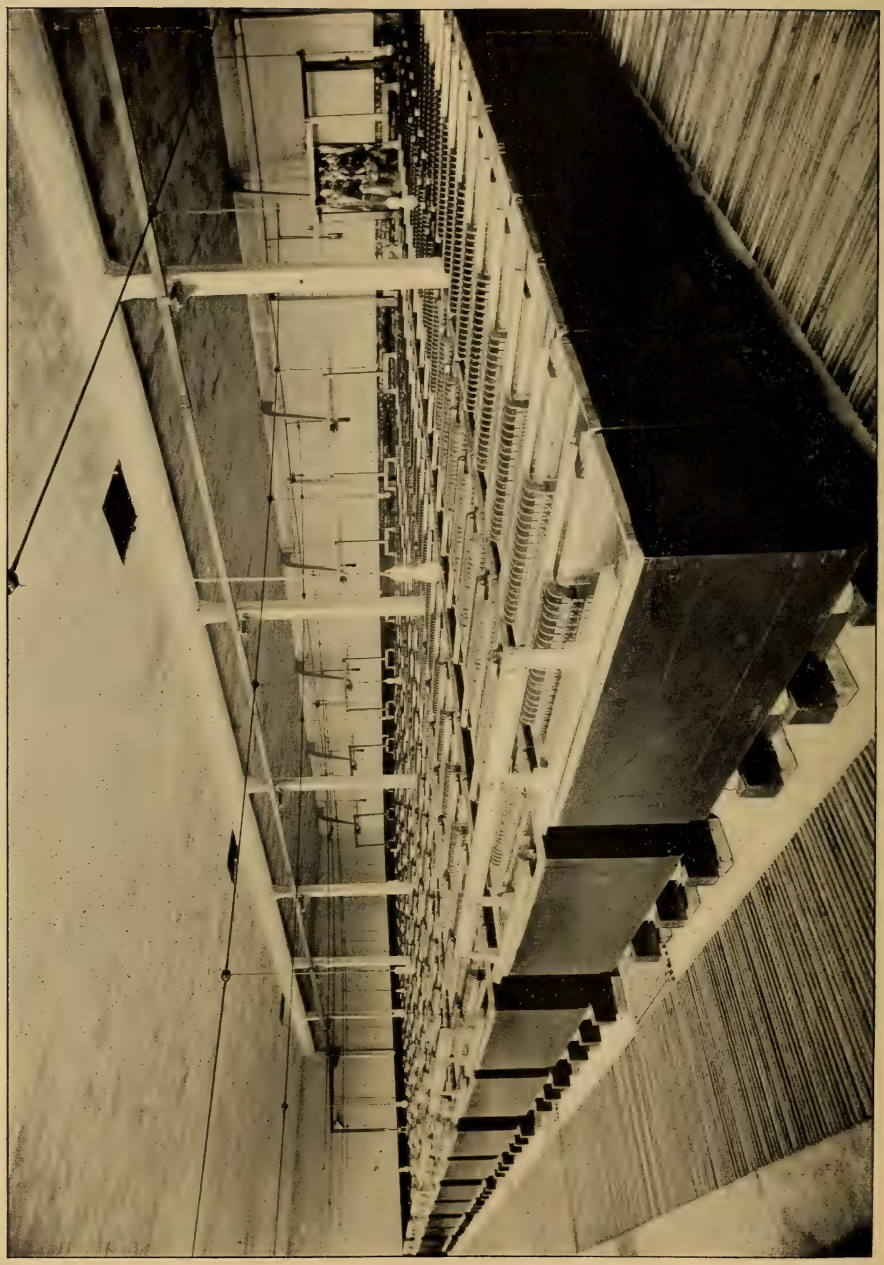


FIG. 6.—STORAGE BATTERY PLANT OF THE BUFFALO STREET RAILWAY COMPANY, N. Y. ULTIMATE CAPACITY, 2000 H. P. AT ONE HOUR'S DISCHARGE

recently made is that in connection with the underground trolley system of the Metropolitan Street Railway Company, in the city of New York. This system covers a large area, and storage batteries have been utilised in substations, two being now in operation.

Each battery plant consists of 540 cells, and each cell contains 51 plates, 15 inches square. The dimensions of the cells are $4' \times 21'' \times 24''$. The battery is divided into two sections, 270 cells in each, which are operated in parallel. This is done to keep the size of the cells within practical limits and to enable them to be more easily inspected and cared for. A cell eight feet in length, which would be the size if only one battery were used, would be too large to be satisfactory. The capacity of the complete battery is 8000 ampère hours, with a one-hour rate of 4000 ampères.

The function of this battery is to take care of a portion of the morning and evening loads, and to take up the fluctuations of load at all times. The method of operation is as follows:—

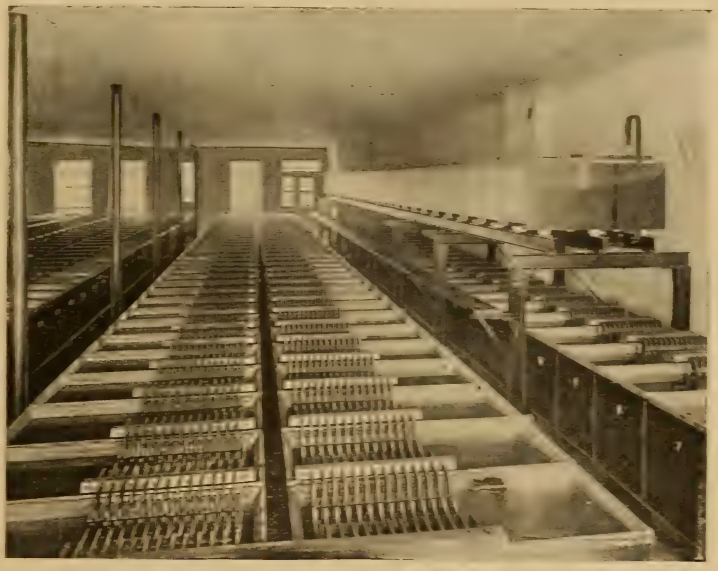


FIG. 7.—ONE OF THE BATTERY ROOMS OF THE SOUTH SIDE ELEVATED RAILWAY AT CHICAGO

Sufficient cells are provided so that the voltage of the battery just balances the average voltage of the system; consequently, when the battery is connected to it, it acts as an equaliser and does not charge or discharge except as the fluctuations occur. When the battery discharges on a peak and is being charged during the hours of light load, a booster is connected in series with it to regulate the amount of charge and discharge. The output of the booster, and consequently the charge and discharge of the battery, is controlled by varying the strength and polarity of the shunt field. This is done by a special form of switch which makes the operation very simple. The daily work of the battery is about as follows:—

From 7 to 9 A. M. it discharges on the peak; from 9 to 12 it floats on the system as an equaliser; from 12 to 3 or 4 P. M. it is charging; from 4 P. M. to 8 P. M. it discharges on the peak; from 8 to 12 midnight it is floating on the system; and after midnight the battery is given its principal charge, this being continued until the battery is full.

A third battery similar to the above is now being installed for the same company, and after the 70,000 H. P. main power alternating current station which is now being built for the company is installed and in operation, each of the present battery stations will be operated in conjunction with rotary converters.

In the electrical equipment of elevated and suburban railways, rapid acceleration is an essential and important feature and makes the storage battery almost indispensable. Large quantities of energy are required for short periods, and such service can be given economi-

FIG. 8.—A TYPICAL STREET RAILWAY BATTERY HOUSE

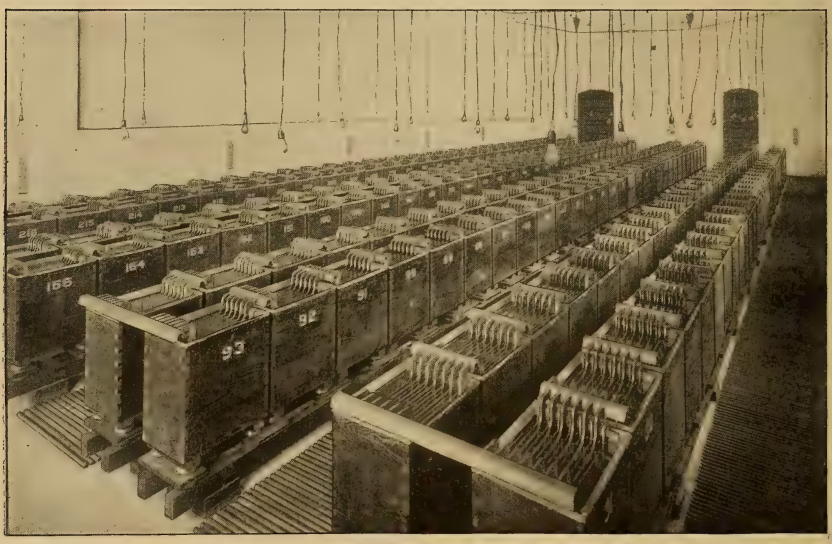


FIG. 9.—AN INTERIOR VIEW

cally only by the use of storage batteries. Such an example is shown in the plant of the South Side Elevated Railway Company, of Chicago, which is fully described in another article in this issue. Recently steam locomotives have been discarded on that line and the Sprague multiple unit system has been adopted. The road is about eight miles long, the power house being approximately in the centre. The two battery substations are located near the ends of the line. They are connected directly across the system, and maintain very good regulation at the power house, keeping the load on the generating plant remarkably constant. The amount of work which the batteries do is controlled by cutting feeders in or out between the power house and the

battery substations. When operating without the batteries, the maximum load was 7500 ampères, with sudden fluctuations of 5300 ampères, while the maximum load with the batteries in use is now 5700 ampères, with sudden fluctuations of only 2000 ampères. Fig. 7 shows one of the battery rooms on the South Side system.

The Buffalo Railway Company installed last year in its Niagara Street power house a large storage battery for the purpose of regulating the fluctuating load due to the 300 or more cars operated from that point, to carry the peak of the load and to serve as a reserve of power in case of the failure of the supply from Niagara Falls. The station contains steam generating units of a total capacity of 7000 H. P., and four rotary transformers, each of about 500 H. P. capacity. These are fed with alternating current at 25 cycles per second from the transmission lines of the Niagara Falls Power Company, and deliver direct current at 550 volts to the railway circuit.

The storage battery consists of 270 cells of forty-one plates, each fifteen and one-half inches square (Fig. 6), having a present capacity of about 1200 H. P. when discharged in one hour. As may be seen from the illustration, the cells are not completely filled with plates, but room has been left for the enlargement of the battery by the addition of extra plates, the ultimate capacity of the tanks being for plates sufficient to give 2000 H. P. at one hour's discharge.

The battery is connected at its positive terminal to the main positive bus of the station, and at its negative terminal, through a motor-driven booster, having a capacity of 2500 ampères at 70 volts, to the ground. The functions of this booster are various, and its construction is worthy of special attention. The motor end is an ordinary six-pole type of motor, working at 500 revolutions per minute from the main bus-bars. It is coupled direct to the compound wound booster, which has two commutators of very large size, each carrying six sets of eight brushes. By this arrangement currents as heavy as 3000 ampères have been sent through the booster without undue sparking.

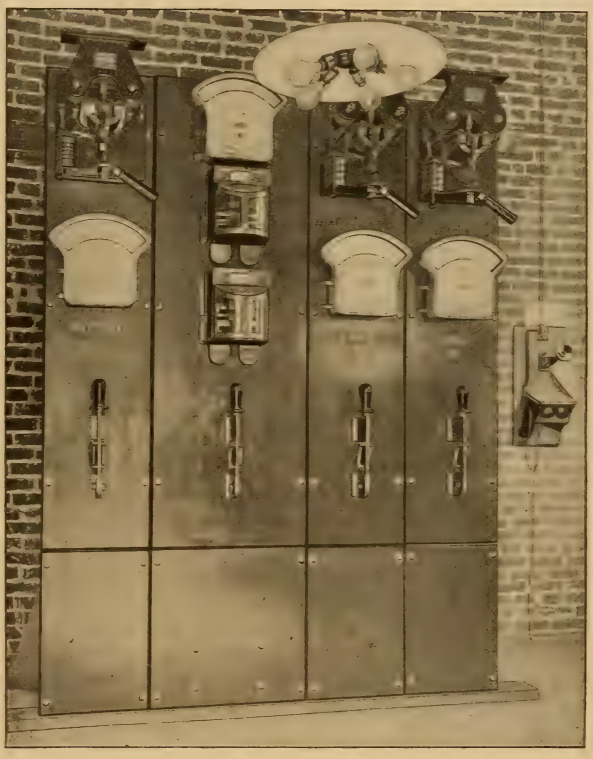


FIG. 10.—A STORAGE BATTERY PLANT SWITCHBOARD

The machine is provided with a centre bearing and the usual self-oiling arrangements, and is, as Fig. 3 shows, of very solid mechanical construction.

As the booster is used sometimes to assist the charging of the cells, and sometimes to help their discharge, it is necessary to vary its terminal voltage from zero to maximum in either direction. This is done by varying the electromotive force at the terminals of the

shunt winding by means of an ingenious switch. In the central position of the switch the electromotive force at the two points of contact with the resistance is the same, and no current flows in the shunt. At either of its terminal positions the shunt is actuated by the full 550 volts, the direction of its magnetisation depending on the position of the switch. The booster can thus be set to either charge or discharge the battery, or in the position of neutral action, by turning the switch lever on the battery switchboard.

During a 24-hours' run the battery is fully charged by the rotary transformers at night and is switched in for service at about 5.30 A. M. The peak at 8 A. M. is taken by the battery, which then runs practically as a regulator until the evening peak comes on. At about 7.30 P. M. the steam engines are shut down and the rotary transformers carry the load until the engines are started again at about 6.30 the next morning. Before the installation of the battery, it was not possible to shut down the engines except from 11 P. M. until 5 A. M., when the load falls off to about 600 H. P. With the battery it is possible to shut down the engines and run on the rotaries alone for 12 hours in each 24, and for 18 hours on Sundays, and the engines are operated on a constant load while running,—the condition of highest economy. During the night all four rotaries in the station are kept fully loaded charging the battery, except from 2 to 5 A. M., when two of them are shut down and the battery is cut off to afford an opportunity to clean the booster and the rotaries. At these hours the two rotaries that are left running carry the whole load.

Fig. 8 shows a battery house built by the Union Traction Company, of Philadelphia, nearly eleven miles from their power station. Fig. 9 represents the interior of the same building, showing the arrangement of the battery. Fig. 10 shows the simplicity of the switchboard. The first panel on the left carries an ammeter, which shows the charge and discharge of the battery; the next carries the wattmeters; and next is the high-pressure feeder panel. This feeder carries practically a constant current, and has a capacity equal only to the average consumption. The ammeter on the panel to the extreme right shows the load on the trolley line, which includes both the current in the high-pressure feeder and the current discharged by the battery. The load varies on the line from 200 to 1200 ampères, while the load on the high-pressure feeder is constant at about 500, the batteries making up the difference.

In plants of this character the attendance is so small that a large number of such stations can be used. To keep such a battery charged, it can be fed from the main power house at a rate equal to the average output in its district. The loss in feeding from the power house can be as high as is most economical from the point of view of balancing energy lost, against interest and depreciation on conductors. This loss is generally so high for any distance of transmission as to make it impossible to operate with it if there were not some means, such as the use of a storage battery at the end of the feeder, to keep the potential constant under conditions of variable output.

If such a substation is installed at a long distance from the power house, the feeder running to it may be economically boosted so as to compensate for the full loss therein. Such a booster, having to pass only the average load at a constant voltage, would be a very cheap and simple machine, and not subject to the difficulty which is met with in series boosters, which it is sought to make automatic in their regulation, and on which the load varies as the square of the current to be transmitted, and the maximum output of which has to be from four to six times as great as that of a shunt booster used in connection with a battery station.

For further distances of transmission to a battery station, rotary converters can be used very economically; they need be only of the capacity of the average output in a district, as the battery takes care of all variations of load and

short overloads. The efficiency of running continually at full load is very much greater than if the machines had to be built for the maximum demands, and run under an average load very much smaller.

With a battery substation it is also possible to employ single-phase transmission with a synchronous motor rotary; this is quite feasible, as the rotary can be started from the battery end and will run steadily loaded, which, of course, is a very great advantage in lessening the cost of line construction and converters.

In fact, no matter what system of transmission is used from a power house to a centre of distribution, a battery at the point of distribution effects a very great economy, as by its use only the average amount of load for such a district need be transmitted to that point; the transmission being at a steady, constant rate, there are no difficulties to be met with in the matter of regulation, which otherwise, with any considerable drop in the line, would cause serious difficulty in operation.

By the aid of a battery the three-wire system may be made perfectly practical and very economical for railway work. If we leave out of consideration the loss in ground return in the railway system, there would be no gain in a three-wire system for railway work, as the length of feeders would be just double what they are in the two-wire system, and the load being divided into halves, the fluctuations on each side would be greater, giving greater difficulty in regulation and requiring more copper for the same maximum drop to the cars.

The gain in the three-wire system is in dispensing with the loss in the return circuit, which, being omitted, can be allowed in the feeders instead, thus decreasing their size; but with a variable load and the system unbalanced, the return would carry about one half the amount of current that it would on the two-wire system, and thus a very small net gain, or no gain at all, is possible.

With the aid of a battery, however, at the feeder ends, and with the middle of the battery connected to the return circuit or neutral, a steady load will be kept on the feeders and the system will be kept balanced through the battery, allowing a gain of from thirty-three to fifty per cent, in conductors, and preventing all danger from electrolysis as well.

ELECTRIC RAILWAYS IN AMERICA

FROM A BUSINESS STANDPOINT

By William J. Clark

THE application of electricity to the propulsion of street cars in the United States is unparalleled in the world's history in the rapidity of its growth, in its attractiveness as an investment, in the revolutionary changes which it has made in the character and methods of local transportation, and in its influence as a re-distributor of urban and suburban population. From a strictly business point of view, no other newly created industry has ever been able to boast that, within ten years of its inception, it gave profitable returns on the enormous total of $1,500,000,000, (£300,000,000).

To-day the trolley cars of the United States carry nearly six times as many passengers as the steam railroads, at approximately one-quarter of the fare per passenger per mile. From 172 electrically propelled cars in operation over 86 miles of street railway track on January 1, 1888, the system has grown until, on January 1, 1899, there were 41,402 cars running over 14,782 miles of track. The classic date in the history of trolley cars is February 3, 1888, when the success of the electric street railway was practically demonstrated by the opening of the first strictly modern line at Richmond, Va.

An achievement so gigantic as these figures indicate can have been accomplished only by men of the greatest energy and ability, having at their command an almost unlimited supply of capital. The complicated problems presented in revolutionising the whole urban and suburban system of transportation in a country of 75,000,000 inhabitants in eleven years have been solved only by the exercise of genius of a high order, not only in the domain of finance, but also in engineering and in the economical organisation and management of large bodies of employees.

Table I. shows the comparative changes which have taken place in street railway transportation in the United States, exclusive of elevated railways, between January 1, 1888 and January 1, 1899.

It will be seen from this table that while the total mileage of street railway tracks in the United States has been trebled during the period under review, electrically equipped lines account not only for all the increase, but also for 4791 miles of tracks upon which horse cars were formerly used. The increase of cable track from 217 to 486 is entirely due to extensions made during the years 1888 and 1889, before the success of electricity as the cheapest motive power for street car operation had been fully demonstrated. Of late years, the building of cable railways for ordinary street railway traffic has entirely ceased in the United States, and two of the largest and most favourably situated lines in

the country,—the Broadway and the Third Avenue cable railways, of New York City,—with a total mileage of 47, are now being electrically equipped.

In order to realise intelligently the present aspect of electrical traction from a business point of view, we must first glance briefly at the transformation which has been effected by the substitution of electricity for horses in the street car systems of the United States. Dealing for the present with the direct changes in the systems themselves, let us compare the radius of action of the average horse car line of 1888 with that of the trolley car line of 1899.

TABLE I.

	1888	1899
Number of roads		
Operated by horses	566	112
" " cable	18	20
" " steam	35	27
" " electricity	21	914
Total	640	1,073
Miles of track		
Horse	5,474	683
Cable	217	486
Steam	216	421
Electric	86	14,782
Total	5,993	16,372
Number of cars		
Horse	21,736	2,86
Cable	2,777	2,920
Steam	238	274
Electric, motor cars	166	33,402
" trail cars	6	8,000
Locomotives	165	130
Total	25,108	47,585
Percentages		
Horse track to total mileage	91.4	4.2
Cable " " "	3 6	3.
Steam " " "	3.6	2.6
Electric " " "	1.4	90.2
Horse cars to total cars	86.6	6.
Cable " " "	11.1	6.2
Steam cars and loc'm's to t'l c's	1.7	.8
Electric cars to total cars	0.6	87.8
Average length of roads	Miles	Miles
Horse	9.67	6.09
Cable	12.06	24.3
Steam	6 17	16.39
Electric	4.09	16.17

The permissible limit of speed with horses, due regard being given to maintenance and renewals, is six miles an hour, including stoppages, and it has been proved, over and over again, by costly experience, that any higher average than this, even in sparsely-settled suburbs, where the stoppages are few, will ultimately show itself in increased operating expenses. But the time limit for transportation of a man who has to spend eight hours or more daily at his business, can never much exceed an hour each way, and we know, as a matter of fact, that in the vast majority of cases, men of this class will change their residence so as to live nearer their employment, if the time spent on their journeys to and fro exceeds three hours daily, or an hour and a half each way. Of course, there are also some business men having shorter hours and a small percentage of those doing a long day's work, who are willing to sacrifice a little more time in order to enjoy the freedom of country life or to secure the cheaper rents which the more remote suburbs offer.

Take it all in all, however, the profitable radius of action of local transportation systems is limited by the time factor to an hour and a half between the inner business zone of a city and its outer residence zone, and in the case of horse cars we have already seen that this time limit implies a distance of nine miles. It must also be noted that the area of the inner or business zone may vary within very wide limits, as we may see clearly in the case of London, where the tram cars are replaced by omnibuses over a central area of about nine square miles, thus marking off what would be called, in the case of any other city, the strictly urban from the suburban districts.

If we now turn to the modern electric trolley car, we can at once see how its profitable radius of action has been extended within our time limit of one hour and a half. Its speed is no longer controlled by the consideration of wear and tear on horses, and there is practically an inexhaustible supply of propulsive power. Nearly all trolley cars now in service weigh at least 20,000 pounds empty, or, with sixty seated passengers, over 30,000 pounds. These cars, equipped with two motors, make an average speed of from eight to ten miles an hour in streets not crowded with vehicular traffic, and a speed of fifteen to eighteen miles an hour in the comparatively unimpeded suburban thoroughfares. In an hour and a half these cars will run a distance of eighteen miles, or double the speed of a horse car. But, doubling the diameter gives us four times the area, so that if we substitute trolley cars for horse cars on any

system, preserving the same time limit as before and extending the tracks to meet the new conditions, we shall give the same accommodation to four times as many people.

Other important consequences follow from raising the limit of speed and increasing the amount of propulsive power which can be applied to each car. Larger and more comfortable cars can be more easily massed to catch the tide of travel, as it flows inwards in the morning and outwards in the afternoon. Trolley cars travel fast enough to produce a feeling of mental exhilaration, which is absent from, or scarcely felt by, passengers in horse cars. The result is that trolley cars attract a far larger amount of what may be called optional patronage than ever horse cars could have done.

The large trolley car, with its fine upholstery and smooth riding, and with its cheap fares for comparatively long distances, offers positive inducements to those to travel who might otherwise stay at home, and more persons go shopping or visiting, or to the theatres or places of recreation. We see the best example of this optional patronage in the free use of the open cars throughout the hot summers in the United States, when mothers take their young children to catch the cool breeze made by the motion of the car, and persons of all ages and both sexes enjoy trolley rides almost as much as they would sleigh rides in the winter.

It follows, therefore, that the increase in gross receipts of trolley cars over horse cars, is accounted for chiefly under two general heads; first, by the increase in the contributory area of population within the same time limit; and, secondly, by the increased facilities and inducements offered to optional travellers.

The indirect results of the substitution of electric propulsion for horse traction have been no less remarkable than those of a direct kind, though they are not so susceptible of precise definition. Speaking in the most general terms, we may say that the growth of trolley car systems tends to give stable business areas to cities, while building up residential districts in suburban areas, because, as we must always remember, the existence in the United States of the tall business buildings,—some of which have as many as 2000 tenants,—is dependent on cheap and quick communication with homes at a moderate rental. The growth of these suburbs has led to the inrush from rural districts of persons with fixed incomes, such as annuitants, widows with young families, and others, who would always have been glad to be within reach of the charm of city life, but who previously were not able to afford it.

This contact with city life has, in turn, brought about a higher standard of taste and comfort among these classes, leading to increased expenditures, and, ultimately, to efforts on the part of boys and girls growing up, to earn larger incomes than would have satisfied them had they remained in the country districts. The net result of all this action and reaction from the particular point of view which we are now considering, has been to increase vastly the number of persons who pay toll to the trolley car systems, either in the course of business or in pursuit of pleasure. Thus the introduction of the trolley car, by cheapening and facilitating the concentration and dispersion of men and women engaged in business, has also increased the urban and suburban population beyond that point by encouraging migration from the outlying rural districts. In this way, too, while increasing the value of suburban real estate, it has made the rental of suburban homes more moderate than they would be by enlarging the area of competition.

The writer has here given what appear to be the most obvious reasons for the enormous increase in gross receipts which the trolley car systems as a whole have caused, as compared with the horse car system which preceded them. Yet, this is not the wonderful part of the story. It might have happened that horse traction might have been succeeded by some other form of mechanical traction,—cable haulage, for exam-

ple,—by which a greater radius of action might have been secured, owing to higher speed, together with larger cars, and better massing of transportation facilities. If this had been the case, large increases in gross receipts might have been witnessed over lines of travel previously well established. Or, we might have seen larger net profits derived from denser traffic, under conditions where the increased cost of maintenance and renewals did not eat up the increase in gross receipts, as is nearly always the case where animal traction is employed. Such changes might have occurred without bringing about the revolution in urban and suburban passenger traffic accomplished by the development of electric traction.

The cable haulage system, which superseded horse traction in certain thickly populated districts, undoubtedly did show itself capable of reaching a fixed limit of cost of operation and maintenance, beyond which any increase in the gross receipts went almost wholly to the side of net profits. But cable lines, by the very nature of their construction and large first cost, were debarred from experimental extension, so to speak; they could not, without throwing away their chief advantage over horse traction, go beyond the traffic already on the ground. The trolley car, on the other hand, could develop new traffic without materially increasing the cost of operation; it could go further into the country than the horse car on account of its higher rate of speed; and it could radiate from a power house like the spokes of a wheel, each new spoke taking, as the beginning of its work, part of the traffic already built up by the older spokes on each side of it.

Most important of all,—and this is what caused its enormous and sudden expansion,—it was found by practical experience that, while gross receipts increased, operating expenses diminished, so that in the State of Massachusetts, for example, which had 533 miles of horse car lines without a single mile of trolley car lines in 1888, the percentage of operating expenses to gross receipts was 81.07; whereas in 1897, when there were 1241 miles of trolley car lines and 61 miles of horse car lines, the percentage of operating expenses to gross receipts had steadily fallen to 68.95, thus leaving an additional 12.02 per cent. of the gross receipts available for distribution as profits, or as payment of interest on bonds.

This fact was so remarkable and so unexpected that many shrewd investors for a long time did not believe such results to be true, and only made to appear so by juggling the accounts, though it is now well established that if the car mileage of any well-managed trolley system be multiplied by three, its fuel account,—in other words, its power,—will need to be multiplied only by two, or, to put it in another way, you can get three times the car mileage for twice the power.

To obtain a thorough understanding of the marvellous success of trolley car operation in the United States, we must dwell on specific instances where practically the same management and financial control of certain systems have been continued for many years, arranging the detailed statements for each year in proper form for comparison. These figures will be given for the period which covers the evolution of each property from animal to electrical traction, thus allowing exact conclusions to be drawn.

The first instance selected for this purpose is an Eastern city in the United States, which, at the commencement of the period shown in the statement below, had a population of approximately 45,000. Its present population, including suburbs reached by its street car lines, is 60,000. The entire street railway system has always been owned by a single corporation, the securities of which have never been watered or juggled in any way. The management of this corporation is known to be ultra-conservative on all questions of accounting, probably to the extent of charging to various operating expenses many items which should properly be entered upon some form of investment account. It should also be stated that the cost of fuel in this locality is very high, and

that the rate of wages is somewhat above the average in other American cities. The table, which we shall call No. 2, is as follows:—

TABLE II.

	1888	1896
Gross receipts	$145,780.00	$521,673.00
Operating expenses	112,647.00	321,585.00
Income from operation	33,133.00	200,088.00
Percentage of operating expenses to gross receipts	77.3	61.6
Miles of track	18.4	60.21
Gross receipts per mile of tr'k.	7,922.82	8,664.22
Gross expen's per mile of tr'k.	6,122.12	5,341.05

The electrical equipment of the system to which Table II. refers was begun in 1890, but was not entirely completed until 1893. Though the population between 1888 and 1896 increased only 33⅓ per cent., the increase in track mileage to accommodate it was from 18.4 to 60.21 miles, or 327 per cent. During the same period, the number of car miles run grew from 475,352 in 1888 to 2,358,622 in 1896,—an increase of over 495 per cent., though the trolley cars in the latter case, having a carrying capacity one-fourth greater than the horse cars in the former, should properly have their car mileage increased by 25 per cent. if we are merely comparing the relative accommodation offered to the public in the two cases. Further, the number of passengers carried in 1888 was 2,714,653, and in 1896 was 10,163,011, an increase of approximately 390 per cent., so that nearly double the space was furnished for each passenger.

Turning now to the financial side of Table II., we find that, though the gross receipts increased onlp 357 per cent., the net income made the tremendous gain of 560 per cent., in spite of the fact that the gross receipts per car mile decreased from 30.62 cents in 1888 to 22.10 cents in 1896, equivalent to a decline of 32 per cent., the wonderful gain in total net income being made possible through a decrease in operating expenses of 43 per cent. per car mile, or from 23.70 cents in 1888 to 13.64 cents in 1896. No clearer demonstration of the business results of electric traction seems needed.

But, to go further, leaving the question of speed out of consideration, what would have been the result if the service of 1896 had been given by horses instead of electricity, assuming that the same number of car miles had been run, the same number of passengers carried, and the same gross receipts collected? Taking the expense of operating by animal traction during 1888 and 1889, when it averaged 22.225 cents per car mile, and multiplying the amount by 2,358,622, the number of car miles run in 1896, we get $524,203.74 as total operating expenses. But we have already seen that the gross receipts for that year were $521,673, so that instead of a surplus of $200,088, as was actually the case with electric traction, we should have had a deficit of $2530 through giving an equally good service with horse traction.

This is the case for electric traction in a nutshell, and the writer's experience allows him confidently to predict that similar results will be found to be approximately true of every extensive street railway in the United States which has discarded horses for electric traction.

The writer next gives, by permission, as Table III., some comparative results of the Lynn and Boston Railroad Company, which is noted for its able and progressive management and also for its extremely conservative methods of book-keeping.

This system was operated entirely by horses in 1891, the change to electric traction having taken place gradually during the years 1892 and 1893. In 1894 only 7.7 miles out of a total of 147.17 were operated by horses, and this form of traction disappeared after the following year. The exact population served by this extremely important system cannot be accurately determined, as its function is to connect the city of Boston with several smaller cities and less important towns which are so closely connected and so thickly populated as to practically form one large urban area. On this account it can hardly be called a suburban system, though this term is often applied to it because the districts which it covers still retain their civic independence of Boston.

In any case, the Lynn and Boston

TABLE III. COMPARATIVE—STATISTICS FOR YEARS ENDING SEPTEMBER 30, 1891, 1894, 1895, 1896 AND 1897, SHOWING BENEFITS OF ELECTRICAL OPERATION OVER HORSE

	1891	1894	1895	1896	1897
Miles operated (less sidings)	62.23	147.17	147.32	149.56	152.92
Gross earnings from operation	$591,903	$1,236,573	$1,376,977	$1,420,702	$1,425,210
Operating expenses	484,947	746,303	784,392	838,328	818,626
Net earnings	106,956	490,269	592,585	582,373	606,584
Percentage of expenses to earnings	81.93	60.35	56.96	59.01	57.34
Earnings per mile operated	$9,510.47	$8,402 12	$9,346 85	$9 499 14	$9,319.98
Expenses per mile operated	7,791.94	5,070.89	5,324.41	5,605.26	5,353.30
Net earnings per mile operated	1,718.53	3,331.23	4,022.44	3,893.88	3,966.68
Car mileage	1,929,523 00	4,528,065.00	4,893,072 00	5,379,210.00	5,480,489.00
Earnings per car mile (cents)	30.67	27.31	28.14	26.41	26.00
Expenses per car mile (cents)	25.13	16.48	16.01	15.59	14.93
Net earnings per car mile (cents)	5.54	10.83	12.11	10.82	11,07

Company thoroughly exemplifies the ideal of American electric street railway traction. If the car mile cost of operating by horse traction in this instance be multiplied by the total car mileage for 1897, as has already been done in the case of Table I., the result would show the insignificant surplus over operating expenses of $47,963, instead of $606,584, which was the actual net income from operation by electric traction.

The writer would now give some tabulated statements of various street car companies, operated by horse traction in 1887, and by electric traction in 1896, the traffic conditions being different in each case.

TABLE IV.—ENTIRE SYSTEM OF AN EASTERN CITY OF ABOUT 60,000 POPULATION

	1887	1896
Gross receipts	$157,813.00	$554,445.00
Operating expenses	131,027.00	356,862.00
Income from operation	26,786.00	197,583.00
Per cent. operating expenses to gross receipts	83.1	64.3
Miles of track	14	34
Gross receipts per mile of tr'k	11,272.36	16,307.60
Operating expenses per mile of track	9,358.76	10,495.94

TABLE V.—THE LARGEST SYSTEM IN A CITY OF APPROXIMATELY 1,000,000 POPULATION

	1887	1896
Gross receipts	$2,441,441.00	$4,604,392.00
Operating expenses	1,881,187.00	2,532,969.00
Income from operation	560,252.00	2,071,423.00
Per cent. operating expenses to gross receipts	77.1	54.3
Miles of track	90	204
Gross receipts per mile of track	27,127.12	22,570.55
Operating expenses per mile of track	20,902.10	12,416.51

TABLE VI.—THE ENTIRE SYSTEM OF A CITY OF MORE THAN 300,000 POPULATION

	1887	1896
Gross receipts	$553,755.00	$1,867,061.00
Operating expenses	422,906.00	1,018,825.00
Income from operation	130,849.00	848,436.00
Per cent. operating expenses to gross receipts	76.3	54.5
Miles of track	52	150
Gross receipts per mile of track	10,649.13	12,447.07
Operating expenses per mile of track	8,132.81	6,790.83

TABLE VII.

	1887	1896
Gross receipts	$31,103.00	$520,171.00
Operating expenses	22,382.00	263,644.00
Income from operation	8,721.00	256,527.00
Per cent. operating expenses to gross receipts	71.7	50.7
Miles of track	3.3	35
Gross receipts per mile of track	9,425.12	14,862.03
Operating expenses per mile of track	6,782.42	7,533.20

TABLE NO. VIII.—A PECULIAR SYSTEM, CONSERVATIVELY MANAGED, AROUND WHICH MANY COMPETING LINES HAVE BEEN BUILT IN A CITY OF APPROXIMATELY 1,000,000 POPULATION

	1887	1896
Gross receipts	$351,588.18	$551,387.72
Operating expenses	270,600.45	336,845.85
Income from operation	80,987.73	214,541.87
Per cent. operating expenses to gross receipts	76.9	61
Miles of track	21.35	18.75
Gross receipts per mile of tr'k	16,467.83	29,514.07
Operating expenses per mile of track	12,674.49	17,965.11

TABLE NO. IX.—A MOST REMARKABLE SYSTEM IN A CITY OF APPROXIMATELY 500,000

	1887	1896
Gross receipts	$178,536.00	$551,780.00
Operating expenses	93,364.00	219,459.00
Income from operation	85,172.00	232,321.00
Per cent. operating expenses to gross receipts	52.2	39.9
Miles of track	12	12
Gross receipts per mile of tr'ck	14,878.00	45,982 00
Operating expenses per mile of track	7,780.00	18,288.00

TABLE NO. X.—A PURELY SUBURBAN SYSTEM CONNECTING SEVERAL TOWNS OF MODERATE SIZE, THAT HAS SHOWN A WONDERFUL DEVELOPMENT

	1887	1896
Gross receipts	$32,843.00	$507,862.00
Operating expenses	15,083.00	232.188.00
Income from operation	17,760.00	275,674.00
Per cent. operating expenses to gross receipts	46.5	45.7
Miles of track	4	65
Gross receipts per mile of track	8,210.00	7,813.00
Operating expenses per mile of track	3,771.00	3,572.00

As will have been noted, the systems, from the reports of which the foregoing brief extracts have been made, show every variety of electric street railway, from those in the largest cities to connecting lines between comparatively small towns.

For the sake of comparison, the writer may now give simular tabulated statements of systems which have been oper-

ated by horses up to the beginning of the present year.

TABLE NO. XI.—IN POINT OF PRESENT RECEIPTS, THE LARGEST REMAINING SYSTEM NOW BEING OPERATED BY ANIMAL TRACTION AND NOW BEING ELECTRICALLY EQUIPPED

	1888	1897
Gross receipts	$831,659.00	$845,919.00
Operating expenses	609,352.00	581,538.00
Income from operation	222,307.00	264,381.00
Per cent. operating expenses to gross receipts	73.3	68.75
Miles of track	17	19 32
Gross receipts per mile of track	48,921.00	43,785.00
Operating expenses per mile of track	35,844.00	30,100.00

TABLE NO. XII. — A SYSTEM SITUATED IN A LARGE CITY AND FREE FROM COMPETITION FROM LINES EQUIPPED WITH MECHANICAL TRACTION

	1888	1897
Gross receipts	$886,736.00	$726,879.00
Operating expenses	566,642.00	531,862.00
Income from operation	320,094.00	195,017.00
Per cent. operating expenses to gross receipts	64	73.2
Miles of track	19	20
Gross receipts per mile of track	46,670.00	36,344.00
Operating expense per mile of track	29,823.00	26,593.00

TABLE NO. XIII. — ONE OF THE VERY FEW SMALL INDEPENDENT HORSE RAILWAY SYSTEMS REMAINING IN A LARGE CITY

	1886	1897
Gross receipts	$24,354.00	$35,066.00
Operating expenses	21,873.00	27,503.00
Income from operation	2,481.00	7,563.00
Per cent. operating expenses to gross receipts	89.8	78.4
Miles of track	3	3
Gross receipts per mile of track	8,118.00	11,689.00
Operating expense per mile of track	7,291.00	9,168.00

It is almost unnecessary to remark, after the disclosure which is made in the statistical summary at the beginning of this article, that street railways operated by horse traction have become so rare comparatively in the United States that they no longer afford instances of the progressive development in economy and efficiency which is so characteristic of all successful American enterprises. Indeed, the figures given in Tables XI., XII. and XIII. show that the systems which still retain animal traction have, on the whole, gone backward, even though they may have benefited by the decline of 50 per cent. in the price of horses which a recent report of the U. S. Agricultural Department shows to have taken place during the past six years. On the other hand, every street railway system which has adopted electricity has made progress, while new systems have sprung up in suburban districts, or for connecting adjacent towns, under circumstances where a horse car service would have been a hopeless financial venture from the beginning.

True, some electric systems have proved to be unsuccessful financial ventures, but electricity, in itself, is not responsible for over-capitalisation, or for the building of roads when the prospect of returns would not warrant their construction, or for the extension of systems to embrace a large and unprofitable trackage. Business judgment, not motive power, is solely responsible for such mistakes in the development of street railways.

The main thing to grasp in comparing the operation of electric with horse traction is that the trolley gives better service with fewer cars, thus cutting down the ratio of expenses to gross receipts in a radical manner not possible with horse cars. Probably no business feature in connection with the value of street railway properties, or their cost of operation, is so frequently overlooked as the importance of large receipts from concentrated trackage. A property showing, for example, gross receipts of $10,000 per mile of track is not simply worth double that which shows similar earnings of $5000, but several times as much, as may be seen by referring to the tables previously given.

Next to heavy gross receipts per mile of track, the most important factor in determining the ratio of operating expenses is the average speed at which cars can be run. It will scarcely seem possible to the average reader that a difference of one mile per hour in this respect may mean the difference between a deficit and a dividend as the result of a year's operation; but the writer is able to show that this is the case by giving the facts from an existing street car system.

Table XIV. shows the number of cars required to operate the service of this system at different speeds, and the average daily cost of operating each car, which is the same in each case, as general expenses are not included, because they are considered a fixed factor, not affected by the number of cars in actual daily service. The importance of good management in preserving schedule

time may also be noted here, because the gain made by running cars at high speed may be thrown away by allowing the cars to bunch so that the traffic will be unevenly distributed and some of the cars will be run at a loss.

TABLE XIV.

At average speed per hour of			Daily expense	Yearly expense
8 miles, requires	63	cars at	$11.80	$743.40	$271,341.00
9 " "	56	" "	11.80	660.80	241,192.00
10 " "	51	" "	11.80	601.80	219,657.00

Next in importance, as affecting net income, to the gross receipts per mile of track, and the speed at which cars are run, is the rate paid for labour. If this rate be higher than the average, the operating expenses bear witness to the fact, because from 70 to 80 per cent. of their entire amount is paid out to employees. The Buffalo Street Railway Company, one of the model systems of the United States, in its report for 1896, shows that over 77 per cent. of its entire operating expenses were spent in this manner, and these figures are approximately true of electric street car systems throughout the United States. In affording employment for labour, the trolley car compares favourably with the horse car, the number of employees on all the street railways of the State of New York having increased 43 per cent. between 1887 and 1896. It is also worthy of note that the Glasgow tramways, owned and worked by the municipal corporation of that city, paid only 43 per cent. of their operating expenses to labour during the year 1895. The average hourly rate of wages in the State of New York in 1896 paid to motormen was 18.3 cents per day of 10.4 hours, and to conductors, 15.9 cents per day of 10.62 hours.

The cost of fuel is next in importance to the amount paid for labour, and this item varies widely according to the distance which it has to be carried and the amount charged for its transportation. In this connection, too, the great economy may be pointed out in the production of power which has been effected in recent years by the substitution of a few large units for a larger number of small ones. Perhaps the limit in this respect has been reached by the Metropolitan Traction Company, of New York City, which is now installing 5000 H. P. steam engines direct connected to 3500 KW. generators, in its new 70,000 H. P. station.

In Table XV. will be found an analysis in detail of the Lynn and Boston Railroad for the years 1896 and 1897, which represents the best American practice, with a tendency to make operating expenses include every possible expenditure which can be charged to that account.

TABLE XV.

	1896	1897
Total number passengers carried	26,791,811	27,386,847
Total number motor and trail car miles run	5,388,806	5,441,766
Total number horse car miles run	90,404	38,723
Total car mileage	5,379,210	5,480,489
Average number cars in use per day of 18 hours	108.9	104.6
Average mileage per car per day of 18 hours	135	143.5
Gross earnings per car mile (cents)	26.41	26.00
Operating expenses per car mile (cents)	15.59	14.93
Net earnings per car mile (cents)	10.82	11.07
Gross earnings per car per day	$35.64	$37.33
Operating expenses per car per day	21.03	21.44
Net earnings per car per day	14.61	15.89
Rate of operating expenses, per cent.	59.01	57.44
Operating Expenses per Car Mile.		
Maintenance of way and buildings (cents)	1.88	2.15
Mainten'ce of equipment (cents)	2.27	1.97
Transportation (cents)	6.92	6.73
Power, electrical (cents)	1.91	1 81
Power, horse (cents)	10.75	9.56
General expenses (cents)	2.46	2.23
Total operating expenses per car mile (cents)	15.59	14.93

The item of State and municipal taxation, which should properly come under the head of fixed charges, has often, though not always, had a part of its burden charged to operating expenses, because many street railway companies are bound by the terms of their franchises to maintain the pavement between and on each side of their tracks.

Differences in methods of book-keeping form, perhaps, the most misleading of all, and the least excusable of any, of the causes of unaccountable discrepancies in comparing the results obtained by different street railway companies. One instance can be cited where a large corporation systematically charges to operating expenses the cost of track extensions, new buildings, and additional rolling stock, all of which are unques-

tionably a permanent investment. Against this another corporation is known which scarcely charges sufficient in the maintenance item of its operating expenses to pay for the oil used in lubricating its machines. These, of course, are the two extremes.

Yet it is believed to-day that the great majority of American street railway companies are making as accurate reports as possible, and are leaning strongly toward conservatism in so doing. In the selection of the tables and illustrations given in this article, the writer has been careful to cite the results of companies which either are rigid in charging to operating expenses everything which properly comes under that head, or which have gone further and charged actual investments to that account.

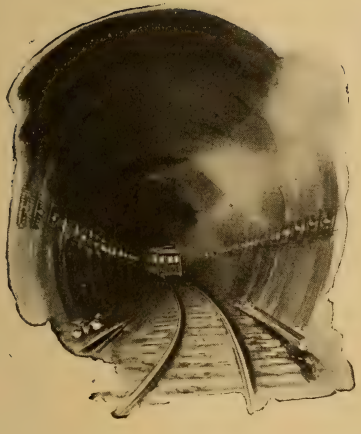
Differences in management can, of course, be held responsible for a thousand details affecting favourably or unfavourably, as the case may be, the business results from the operation of any street railway system. The handling of employees, the selection of subordinate officials, the purchase of materials and supplies, the engineering ability displayed, the relationship of the corporation to the public, the adjustment of routes and the adequacy of the service to meet the public demands, the selection of rolling stock to best meet the requirements of a particular service, maintenance,—all these rest ultimately upon the management, which has thus abundant room for the display of individual ability and energy.

The vast strides which electric street railways have recently made in the United States have already been shown in Table I., at the beginning of this article. While statistics are, unfortunately, not available to show the average percentage of operating expenses to gross receipts on the larger horse car lines of ten years ago, it is believed by those most competent to judge that this average did not fall below 80 per cent. For the year 1896 the average ratio of operating expenses to gross receipts on all electric street car systems in the United States with annual gross receipts of $100,000 or more, was only 56 per cent. And there is ample reason for believing that, with average conditions of traffic, any system, constructed and equipped throughout according to the most recent practice, will show a ratio of not more than 50 per cent. of operating expenses to gross receipts.

A TRAIN AND LOCOMOTIVE ON THE CITY AND SOUTH LONDON UNDERGROUND ROAD

THE CITY AND SOUTH LONDON ELECTRIC RAILWAY

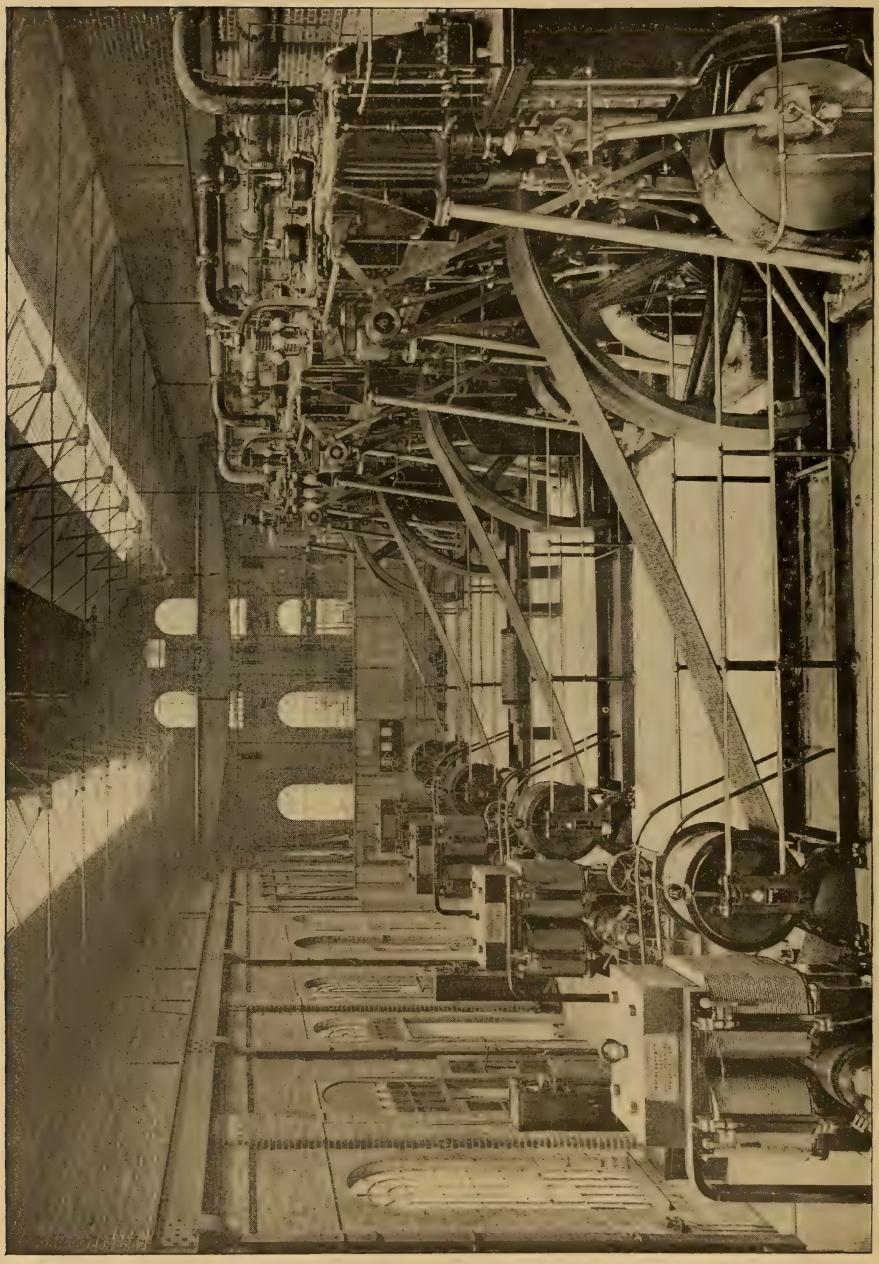
By P. V. McMahon, A. M. I. C. E., M. I. E. E.
Chief Engineer



IN 1884 an act of Parliament was passed, after considerable opposition, authorising the construction of the City of London and Southwork Subway between King William St. and the Elephant and Castle. In 1887 an act sanctioning the extension of the subway to Stockwell was obtained. The act authorising the extension to Clapham Common was passed in 1890, and the name of the undertaking was changed to the City & South London Railway. The extension of the line to Islington was authorised by the act of 1893, and was followed by other acts for extension of time for the construction of the Clapham Common and Islington extensions.

The line is constructed on what is now known as the Greathead system of tunnelling. The work was started in October, 1886, by sinking a shaft in the river behind the old Swan Pier, near London Bridge. The tunnels were driven from this shaft under the river and completed by the following June. In the following month tunnelling operations were started at the Borough station, and the line was completed in 1890. The opening ceremony by H. R. H., the Prince of Wales, took place in November of that year, and the line was opened for public traffic on December 18. Since that date it has safely carried over 50 million passengers, exclusive of season ticket holders.

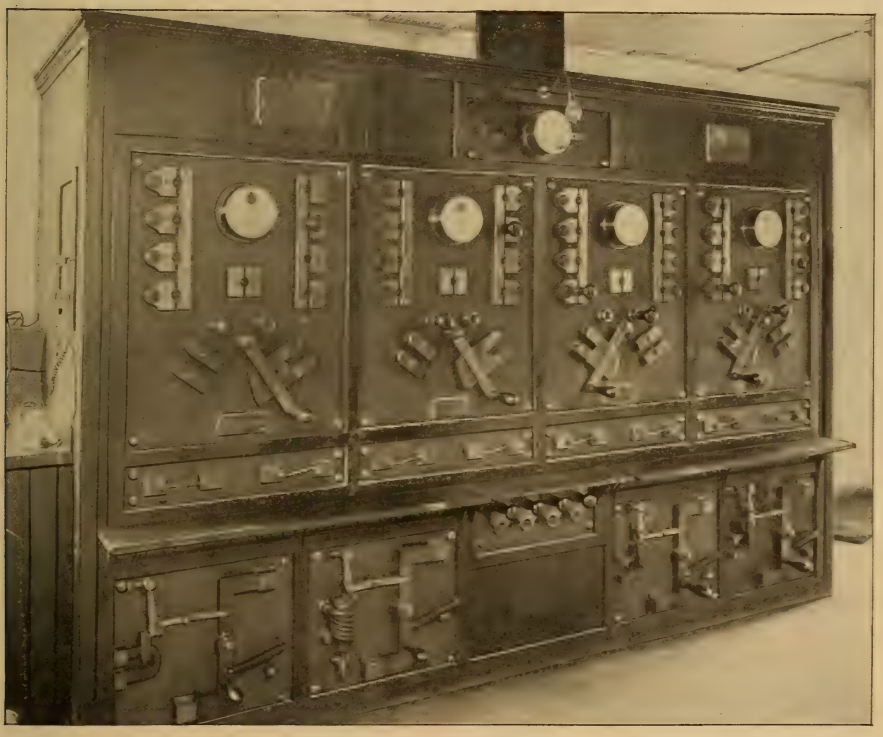
The railway as at present constructed is a little over three miles long, and runs, as already stated, from Stockwell



THE POWER HOUSE OF THE CITY AND SOUTH LONDON RAILWAY

to King William Street. There are five intermediate stations, as shown on the map on page 531 the average distance between each station being about 2900 feet. The two tunnels are constructed of cast iron, built up in segments and bolted together, the internal diameter of the tunnel from Stockwell to the Elephant and Castle being 10 feet 6 inches, and from the Elephant and Castle to the city, 10 feet 2 inches. It may be interesting to state that in the construction of the tunnels about 28,000 tons of cast iron were used, and the excavation necessitated the removal of 184,000 tons of London clay.

The 60-pound rails are laid on cross sleepers, the latter being cut to fit the sweep of the tunnels, and resting on the sides without ballast. Between the third rail or working conductor and the ordinary rail a footboard, 18 inches wide,



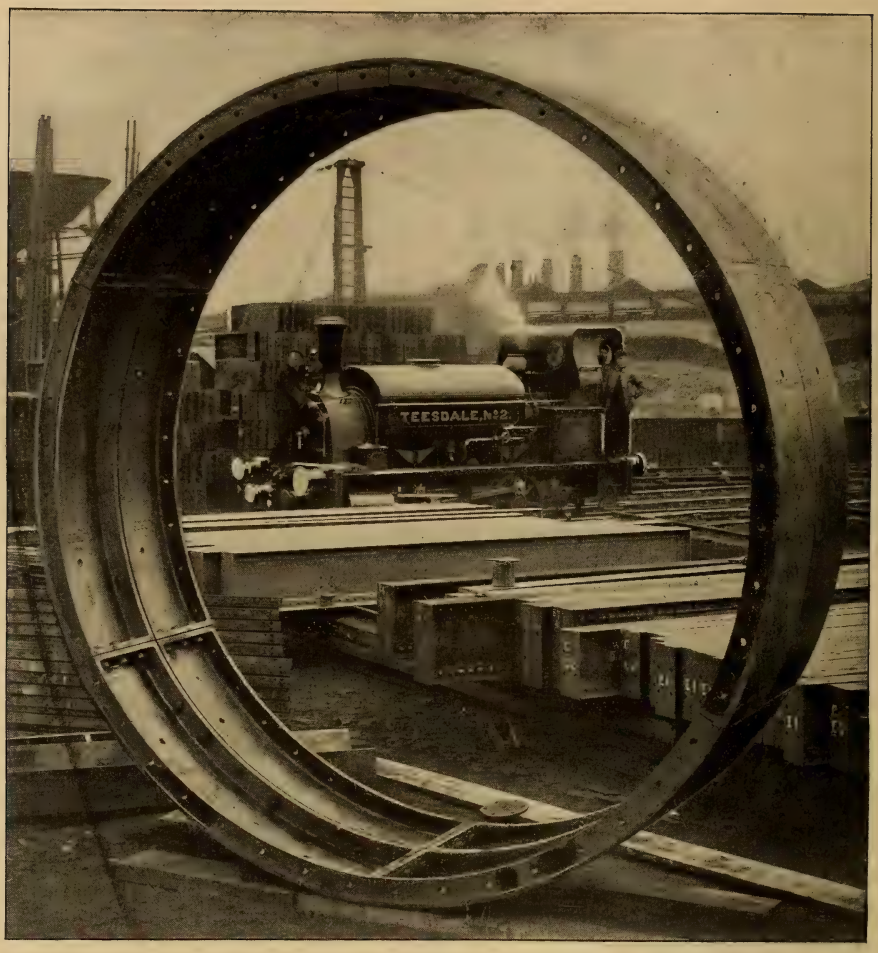
THE MAIN SWITCH BOARD

The railway runs under the streets at an average depth of 60 feet, the rail level at Stockwell being 49 feet below the surface of the road and 69 feet at the City station.

The tunnels are driven side by side almost entirely the whole length of the line, the exception being between the Elephant and Castle and the Borough stations, where one tunnel crosses the other, and between the Borough and the City stations under the river Thames, where the tunnels again cross.

is laid. The running rails form the return conductor, and, in addition to the fish-plates, are bonded at each joint by two flexible copper strips, riveted to the flange under each joint.

The working conductor is special, high-conductivity channel steel, ½ square inch in section, supported on glass insulators. It is rolled in 24-foot lengths and joined by a pair of fish-plates. To bring the conductivity of the joints up to that of the solid rail, copper strips, similar to the rail bonds,



ONE OF THE RINGS FORMING THE TUNNEL LINING. SUPPLIED BY MESSRS. HEAD, WRIGHTSON & CO., LTD., LONDON

are riveted inside the channel. The resistance of the third rail, per mile, is 0.27 ohm, and is practically equivalent to the solid rail without joints.

The diagram of connections on page 537 shows the general arrangement of feeders and connections. There are four lead-covered cables each of 0.30 square inch sectional area. These cables are supported by iron brackets, bolted to the sides of the tunnels, and insulated therefrom by wooden insulators. The feeding points are at the Oval and the Borough stations.

As shown in the diagram mentioned, the third rail is divided up into sections and connected through fuse boards in the signal cabins. In this manner any desired combination of feeding points can be obtained, and the line can be divided into sections for testing and other purposes. In the diagram the running rails are omitted for the sake of clearness; the thick lines represent the working conductor, and the arrows distinguish between the up and down roads. The thin lines represent the feeders, and at the right are shown the dynamos, switchboard and rail connections.

One other interesting feature in connection with the third rail may be mentioned. On account of the angle of the

scissors crossing at Stockwell, the locomotive shoes or collectors in passing over the running rail would touch the latter, unless held up while crossing over, and this object is attained by the movable conductor or electric bridge, operated from the signal box and interlocked with the points. The sketch of the crossing on page 539 is self-explanatory, and the bridge is set for a train to cross from No. 1 platform to the up road. The insulation resistance of the whole system is such that, with 500 volts, the leakage current is only 0.5 ampère.

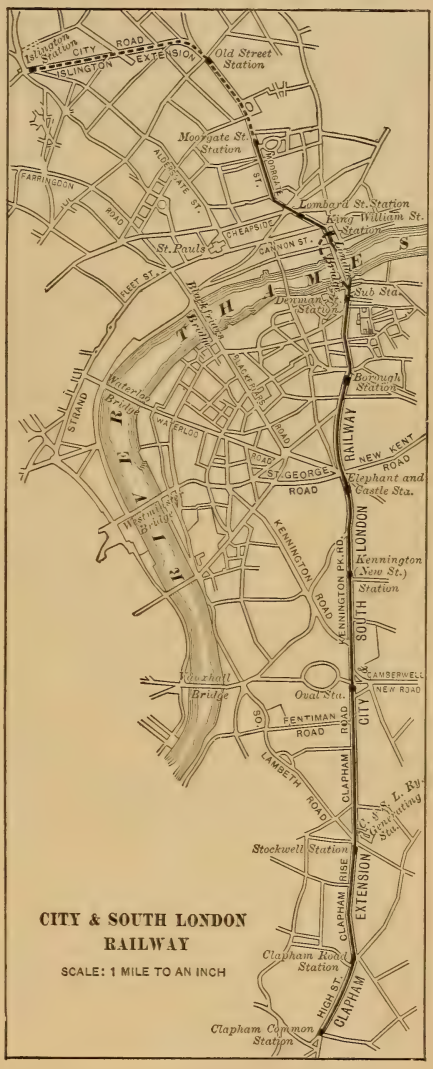
The depot containing the generating station, repair shops and carriage sheds, is situated at the Stockwell end of the line, and is connected to the railway by a tunnel about 100 yards long, rising from Stockwell station to the surface with a gradient of 1 in 3½. The locomotives and carriages to be repaired and overhauled are pulled up this incline by a winding engine.

The generating station is a brick building 141 feet long by 44 feet wide with 25 feet from the floor to the traveller. This building contains the main generating engines and dynamos, the hydraulic engines, and the necessary tools for repairs connected with the locomotives and other parts of the equipment. The generating plant consists of four vertical compound engines of 425 I. H. P. each, driving, by link belting, four Edison-Hopkinson compound dynamos having an output of 450 ampères at 500 volts.

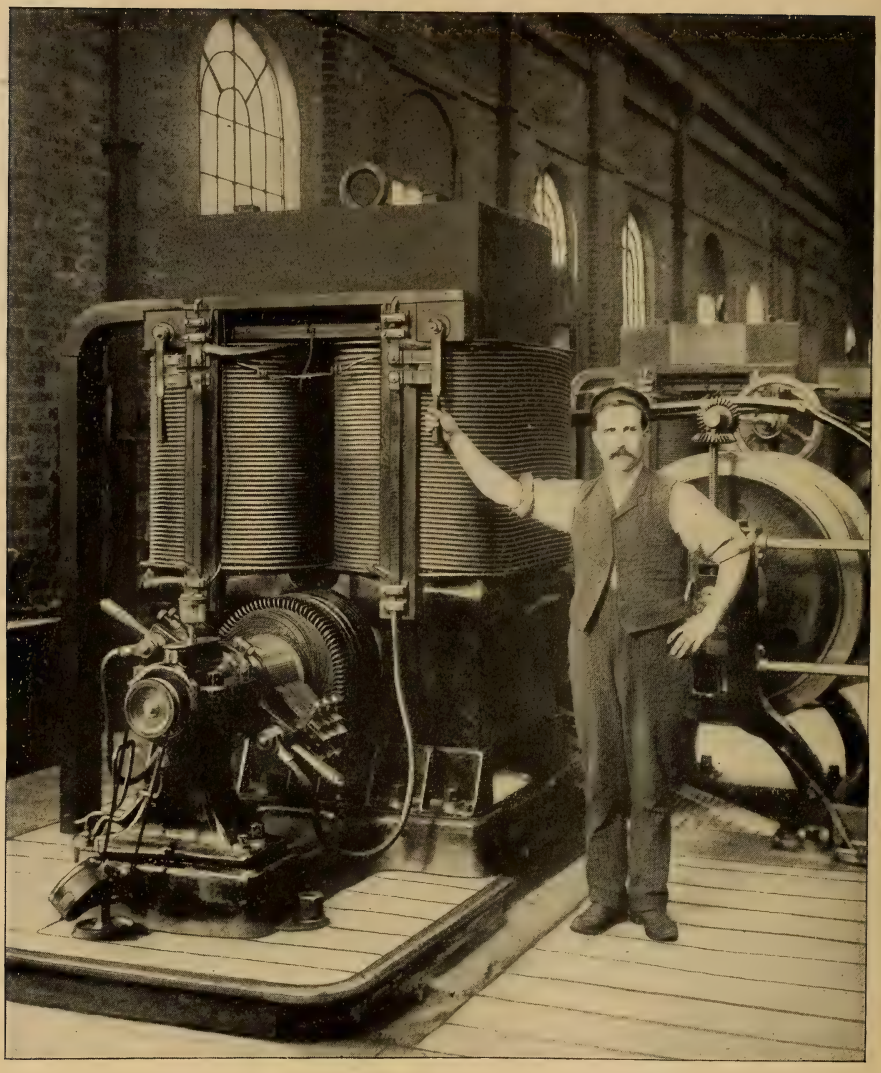
Between the second and third engines is placed a direct-coupled Siemens-Willans set, having an output of 240 ampères at 500 volts. In passing, it may be mentioned that this is the first direct-coupled set used in the United Kingdom for traction, and has given every satisfaction since its erection. The photograph on page 528, giving a view of the engines and generator from the gallery, was taken before this direct-coupled set was put down, but it now stands in the position occupied by the spare generator armature shown in the illustration.

The boiler house is underground, and contains eight Lancashire boilers, each 28 feet long and 7 feet 6 inches in diameter, working at a pressure of 140 pounds per square inch, and equipped with mechanical stokers. The coal is delivered into the hoppers over the stokers from carts at the ground level.

Towards the end of the year 1896 a separate condensing plant was erected.



This consists of an independent jet condenser and air pump, arranged tandem fashion, with the fly-wheel between the steam cylinder and the air pump. On account of the small supply of water available, a cooling tower is used in



AN EDISON-HOPKINSON GENERATOR IN THE POWER STATION

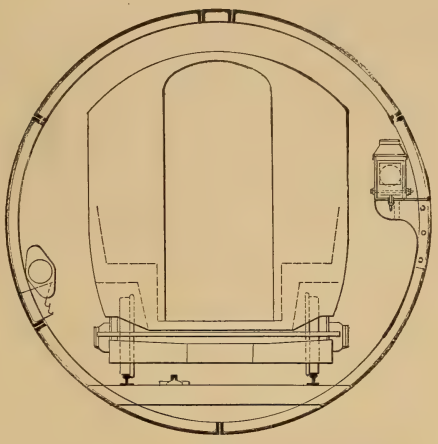
connection with the plant. This tower is 25 feet in diameter and stands about 50 feet high.

At a level of about 7 feet from the ground a series of small nozzles with eight holes, about 1-16 inch in diameter, are arranged, and over each nozzle is placed a double funnel-shaped pipe, about 2 feet high. The overflow water from the hot well is forced through these nozzles by a centrifugal pump, placed alongside the air pump, and driven by a Chandler high-speed engine. A pressure of 20 pounds per square inch is maintained at the circulating pump, and the quantity of water passing through the tower is about 1500 gallons per minute.

Underneath the tower a circular tank, holding 50,000 gallons, catches the water and acts as a storage supply from which injection water may be obtained for a short time in case the circulating pump should be shut down. The water leaving the nozzles is divided into very small particles and rises in the tower

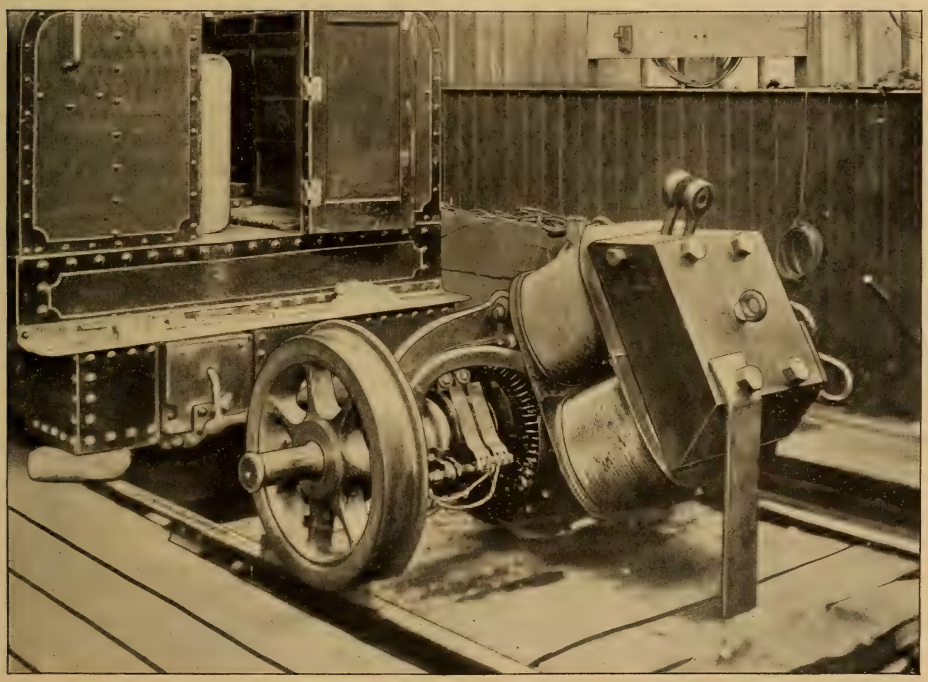
about 20 feet. The tubes over the nozzles act as a sort of air injector and thus an up-draught is formed. The temperature of the water entering the tower averages 128° F., and is cooled to 98° F. The average vacuum is 22 inches of mercury.

The switch room stand is in a small building to the left, and contains the switchboard. As can be seen from the illustration on page 529 the board contains four panels; each panel has an ammeter and main switch; the vertical screw plug contacts to the right and left are the positive poles of the various dynamos. To couple any dynamo to the feeder, the required machine is first connected by the screw plug to one of the switch contacts; the switch is then thrown over from the middle position, and the circuit is completed through the ammeter to the feeder. The bus bars



CROSS SECTION OF ONE OF THE TUNNELS

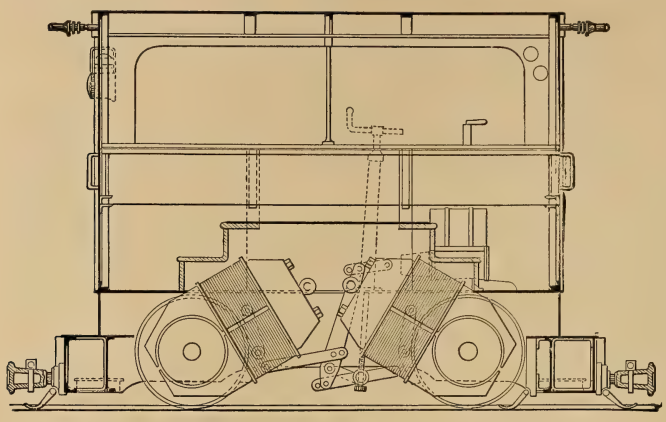
breakers are in the dynamo circuit, and are arranged on the bottom of the board. The circuit is not really broken,



THE MOTOR OF ONE OF THE LOCOMOTIVES BUILT BY MESSRS. SIEMENS BROS. & CO., LTD., LONDON

from the dynamos run horizontally at the back of the board, and each feeder is connected up as already described.

The automatic cut-outs or circuit as in American practice, but a resistance is inserted of such value that with a dead "short circuit" on the line the current from any one machine is limited



ELEVATION AND SECTION OF A MATHER & PLATT LOCOMOTIVE

to its maximum value. In this manner it can be seen from the ammeter when the "short" is removed.

The next and perhaps most important item in the system is the electric locomotive, for upon its satisfactory and economical working depends to a very great extent the success of the railway. The line was opened for traffic with fourteen locomotives made by Messrs. Mather & Platt, Ltd., of Manchester. One of these was a geared locomotive, to which reference will again be made. The armatures in the locomotives now in regular service are wound directly on the axles. The locomotive, complete, weighs 10.35 tons, has a wheel base of 6 feet, with wheels 27 inches in diameter, and has the following over-all dimensions:—Length from buffer to buffer, 14 feet; height above rail level, 8 feet 5½ inches; extreme width, 6 feet 10 inches.

The two motors are permanently coupled in series and are controlled by a plain rheostat switch with twenty-six

ONE OF THE ELECTRIC LOCOMOTIVES BUILT BY MESSRS. MATHER & PLATT, LTD., MANCHESTER

AN END VIEW

contacts; there is also a reversing switch for reversing the current in the armatures. Each locomotive is fitted with the Westinghouse air brake, the air reservoirs being circular cylinders placed on each side of the cab. The capacity of these cylinders is about 18 cubic feet. A charge of air is taken from a main reservoir at Stockwell station before starting each trip. This reservoir is fed by Westinghouse air pumps fixed in the power house. A powerful hand brake is also fitted to each locomotive.

The starting current is 150 ampères, and the actual draw-bar pull at starting, as measured by a dynamometer, is 2050 pounds. The average running current is 50 ampères, and on the level the draw-bar pull actually measured is 400 pounds, the speed being about 17 miles per hour. Although troubles have been experienced with these locomotives, principally due to failures of armature

THE INTERIOR OF ONE OF THE CARRIAGES

winding, they have run upwards of 400,000 miles each in actual service.

The rewinding of an armature, to the ordinary mind, or even to the average electrical engineer, is a serious matter; but when it is said that most of these armatures run 150,000 miles before rewinding becomes necessary, it will be seen that it is not such a heavy item. The average life of an armature is over 100,000 miles before rewinding, and the cost works out at 0.03 of a penny per mile run.

Experience shows that in no case can the armature failures be traced to having the armature directly secured to the axle of the locomotive. In the case of the geared locomotive, already referred to, armature troubles are just as frequent as in the gearless locomotives, and the gearing makes such a noise that this locomotive is kept

as a spare one, and is used for shunting.

In the working of the line it was soon found that additional locomotives were required, and two were ordered from Messrs. Siemens Brothers & Co., Ltd., of London. The essential difference between these two and the earlier locomotives is that the Mather & Platt machines have Gramme-wound armatures, while the Siemens locomotives are drum-wound. The latter also weigh 13.5 tons each complete. The switching arrangement and brake gear are practically the same in both types of locomotive. The Siemens machines are more powerful than their predecessors, the draw-bar pull for 150 ampères being 2870 pounds. The draw-bar pull on the level for 50 ampères is 500 pounds at about 16 miles per hour; in both cases the pull was measured with a dynamometer.

In actual working there is not much difference in the performance of the two types of locomotive, the gain in draw-bar pull being, to a certain extent, counterbalanced by a lower speed for the same current. The time taken to run over a section is, however, practically the same with both, so the Siemens type gets up to full speed in a shorter time than the Mather & Platt type.

The next locomotive, No. 17, was built by the company in their own works at Stockwell, and in its construction the experience gained with the first types was turned to account. This machine weighs 11 tons, 12 cwt., gives a draw-bar pull of 2220 pounds for 150 ampères at starting, and for 50 ampères the pull is 450 pounds, both measured with dynamometer.

In view of the additional locomotives required for the Moorgate Street and Clapham Common extensions, it was thought that the existing locomotives could be improved, and early in 1897 some experiments were made. The space at the disposal of the author will not admit of his going into these, but it will suffice to say that one of the Mather & Platt locomotives was reconstructed as the result. The armature and magnets were removed for series-parallel working, and a new form of series-parallel switch, suitable for locomotive work, was developed. The switch is very similar to, and is operated in al-

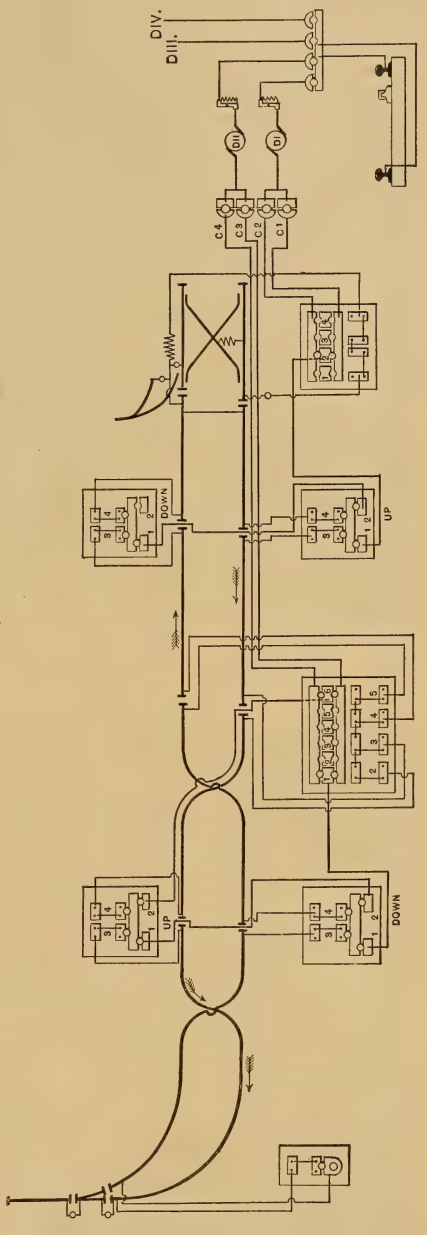
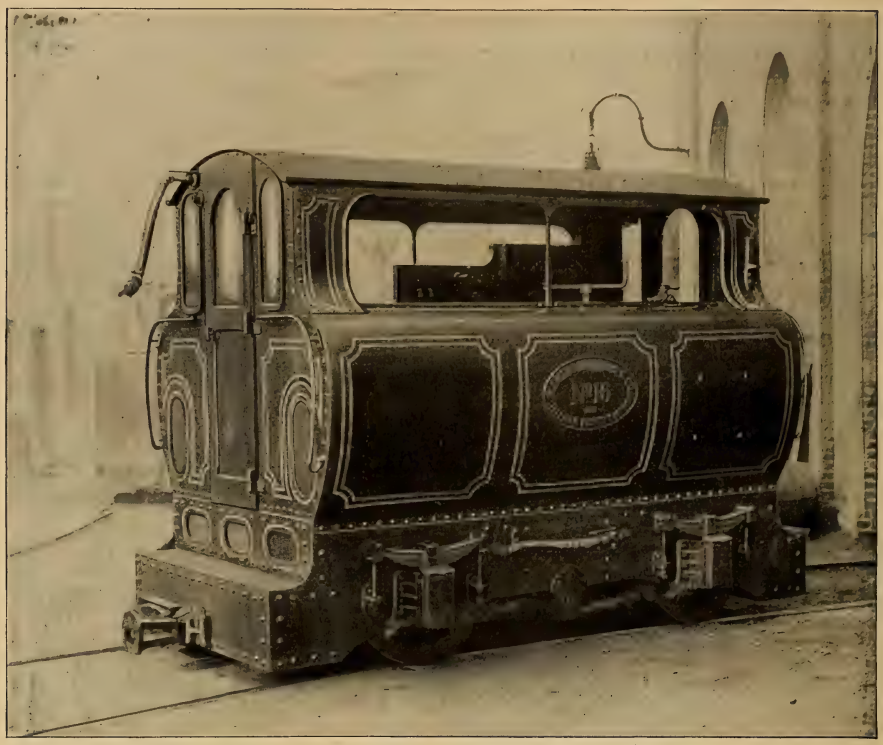
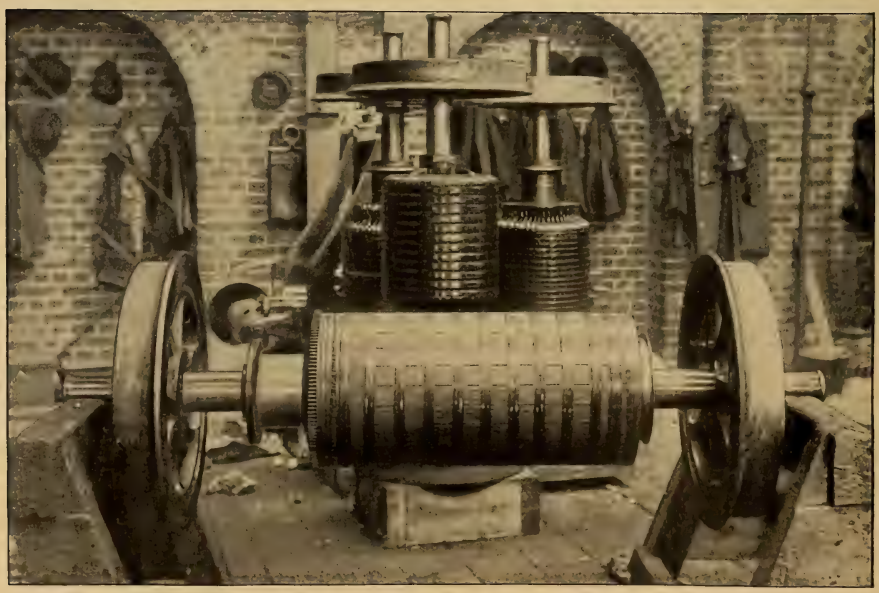


DIAGRAM OF LINE CONNECTIONS

most the same manner as, the ordinary rheostat switch. There is no magnetic blow-out or equivalent device, and in



ONE OF THE LOCOMOTIVES SUPPLIED BY MESSRS. SIEMENS BROS. & CO., LTD.



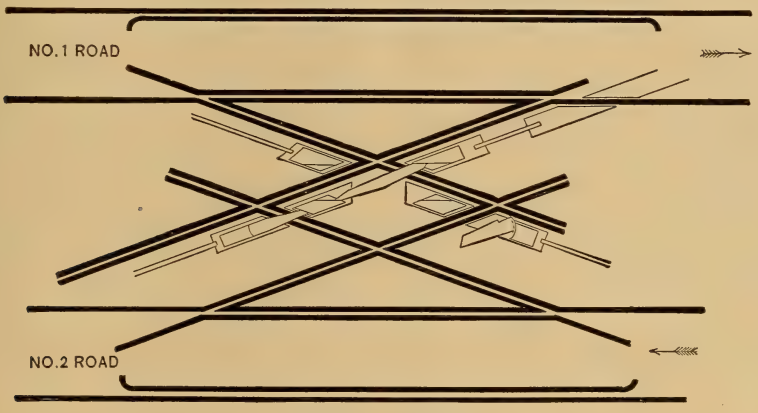
ARMATURES OF THE SIEMENS LOCOMOTIVES

actual work this series parallel controller has shown that it is eminently suitable for heavy locomotive work.

To appreciate the improvement made in this locomotive by the alteration briefly sketched above, a few words must be said upon the efficiency of the electric locomotives in ordinary work. The distance between stations being very short, and a quick service of trains a necessity, the amount of power spent in getting the trains up to speed is naturally a very large percentage of the total power required. Dividing a run between stations into two periods,—a starting period, or the time from which current is switched on and until full speed is attained,—and a running period, or the time from which full speed is attained until the brakes are applied, it was found that the efficency of the locomotive, or the relation between the electrical energy drawn from the power house and the mechanical energy given out at the draw-bar, was, before the alteration, 29 per cent. during the starting period, and 73.4 per cent. during the running period; when altered, the same locomotive had an efficiency of 46.1 per cent. at starting and 70.6 per cent. in running.

The best results obtained with express locomotives of which the author is aware, is an efficiency of 64 per cent.; that is, 64 per cent. of the indicated horse-power in the cylinder appears as useful horse-power at the tender draw-traveller is not inclined to give any bar. From the author's experience with electrical locomotives, he has no doubt that the efficiency of such a locomotive, built for long runs,—say, 5 miles without stops,—can be brought up to 80 per cent. All the new locomotives for the extension are being built upon the lines of the altered locomotive, and three of these new machines are now in service.

In addition to carrying passengers in a horizontal direction, the railway here considered has also to carry its patrons vertically, and although the average credit for being shot upwards, the machinery required for this purpose forms not an unimportant part of the company's equipment. In one day the lifts at King William Street station travel upwards of 10 miles vertically.



A SCISSORS CROSSING

The hydraulic plant, installed by Sir W. G. Armstrong, Whitworth & Co., of Newcastle-on-Tyne, consists of three compound pumping engines of 100 H. P. each, two of which do the work, the third being kept as a reserve. The water is pumped into the mains at a pressure of 1240 pounds per square inch. Close to the pumping engines at Stockwell the main accumulator is placed, a smaller accumulator being at the Elephant and Castle station. The water is all returned to the power house and is used over again.

There are, in all, twelve lifts, two at each station, and each lift capable of carrying 50 persons. The tunnels are

drained by hydraulic ejectors worked from the high-pressure mains, the water being returned to the power house. At the depot the capstans for shunting purposes and the locomotive repairing shop lift are also worked from the hydraulic system.

To the enthusiastic electrical engineer it may seem strange that electric lifts were not installed; but it must be borne in mind that, twelve years ago, electrical lifts were almost unknown. The City and South London Railway is not, however, behind the times, and in the summer of 1897 they determined to try electrical lifts, and decided to convert one of the hydraulic lifts at Kennington into an electrical one. Messrs. Easton, Anderson & Goolden, Ltd., at Erith, were entrusted with the work, which, owing to the engineering strike, was delayed. But this lift is now working satisfactorily, and in consequence all the lifts on the extension, seventeen in number, are to be electric. Two of these lifts will have a capacity of 75 persons each, and the speed will be 180 feet per minute. They will be supplied with current from the same mains as the locomotives.

The signalling and electric locking arrangement to insure protection to the trains are probably the most perfect in the world. In addition to a very complete system of mechanical interlocking of levers, the starting and all important signals are also electrically locked and controlled by the station in advance of the train. In this manner the signalman is unable to lower a signal and let a train at, say, *A*, start until the preceding train has passed out of the station *B* in advance. At the Stockwell terminus 450 trains pass in and out, exclusive of shunting, in one day. This entails about 10,000 movements of levers and electrical contacts, and is all done by one man.

The extensions of the City and South London Railway are progressing rapidly. The new tunnels between the Borough and Moorgate station are complete, and about half of the tunneling on the Clapham extension has been done. When these extensions are open, it is proposed to run a two-minute service of four-coach trains between Clapham Common and Moorgate Street. To cope with this increased and rapid train service, a new power house is being built at Stockwell, having an output of 3500 I. H. P. The method of distributing the electrical energy to the locomotives will be changed from the ordinary two-wire system to a three-wire system, with a substation at London Bridge containing a large storage battery. Balancing transformers will also be placed at the two ends and the middle of the line.

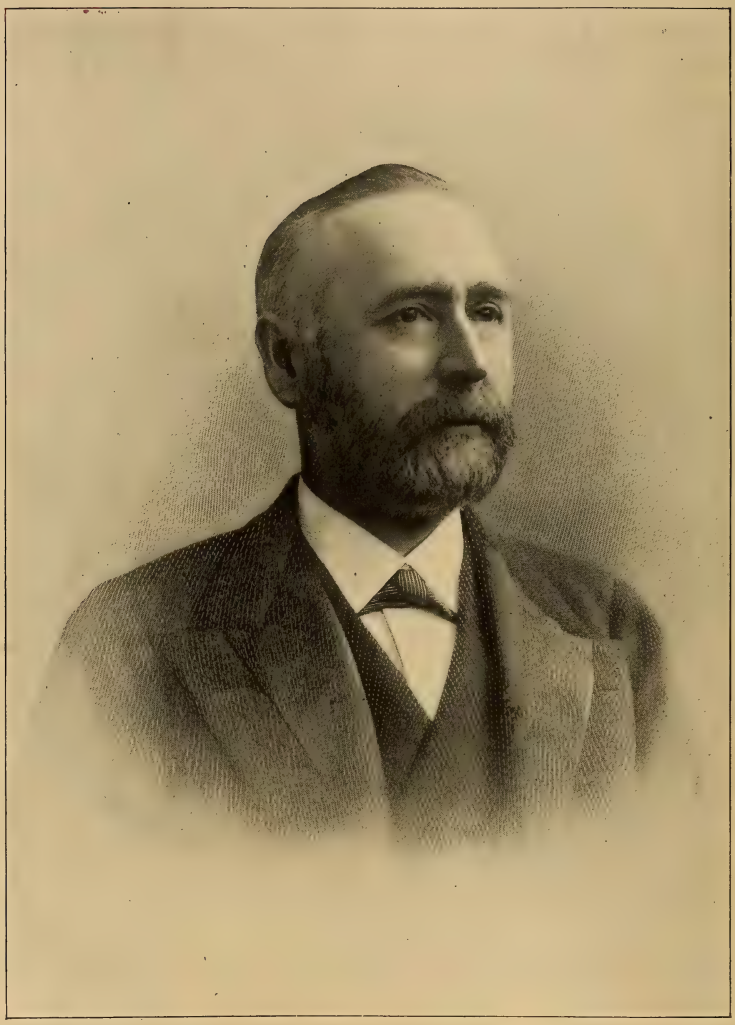


PHOTO BY LAFAYETTE, LTD., DUBLIN.

Yours very truly,
W. J. Pirrie

THE DESIGNER AND BUILDER OF THE WHITE STAR LINE STEAMER "OCEANIC," THE LARGEST VESSEL AFLOAT

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VOL. XVI SEPTEMBER, 1899 No. 5

AMERICAN LOCOMOTIVES IN GREAT BRITAIN

By Charles H. Jones, Assistant Locomotive Superintendent of the Midland Railway

PUTTING THE ENGINES TOGETHER IN THE YARD OF THE MIDLAND LOCOMOTIVE WORKS AT DERBY

THE announcement, not long ago, that a large order for locomotives had been placed in America by one of the leading English railway companies was somewhat startling. Many Englishmen regarded it as an unpardonable intrusion for foreign engines to be brought to Great Britain,—the birthplace of locomotives and of Stephenson, the father of them. If the directors of the Midland Railway Company could have avoided it, they certainly would not have wounded the susceptibilities of these people, but exceptional circumstances rendered it necessary. Sir Ernest Paget, in his speech to the Midland shareholders at their meeting at Derby, on February 17, this year, put the case very clearly. He said:—

"You will no doubt have seen that we have been purchasing some engines in America. As this is a new departure,

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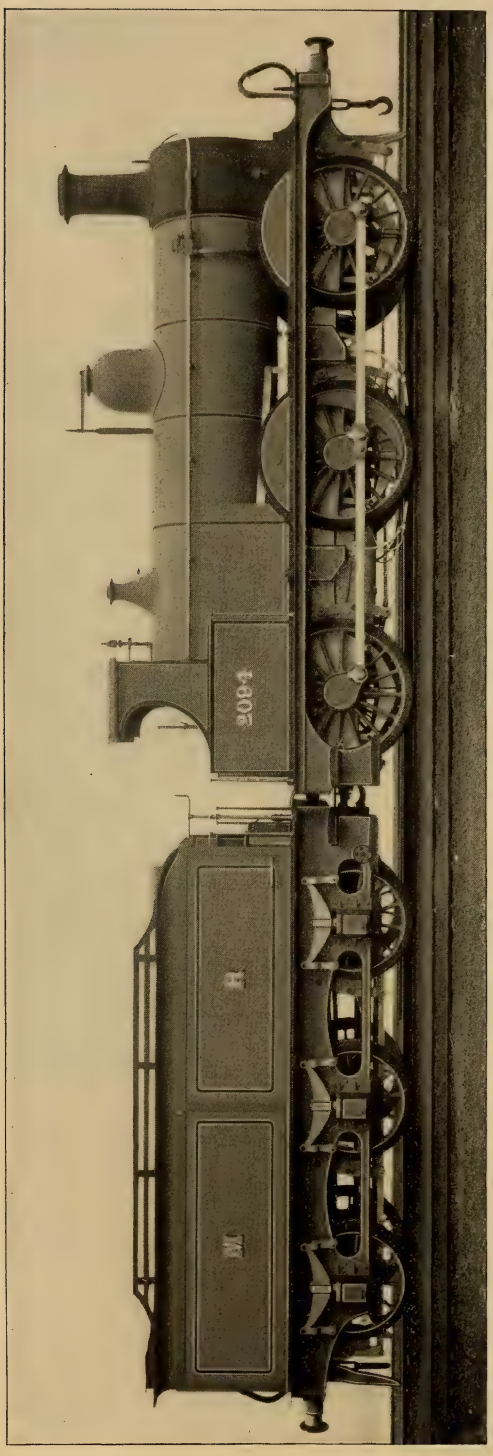


A STANDARD GOODS ENGINE ON THE MIDLAND RAILWAY

some explanation will be interesting to you. We should very much prefer to purchase home-made goods, whether it be engines or anything else, if it were possible. The question of cost did not enter at all into our calculations when we asked for tenders for engines from over the water. Our train mileage has been increasing very rapidly of late years,—the train mileage in this last year of 1898 increased by more than 2,000,000 miles. Our locomotive superintendent, Mr. Johnson, has for some years been impressing upon us that we work our engines too hard. I believe that if he had his way he would have about 75 per cent. of them in steam; as it is, 90 per cent. is much nearer the number, so that you will see that there is no margin there.

"We have at present 170 engines ordered in England. The orders commenced in December, 1897. The first engines were to be delivered in July, 1898, at so many per month, and if that delivery had gone on properly we should now have forty-eight of those engines. We have not received one. The last order we gave, in December, 1898, was for twenty engines at a very large cost, and we could not get even the promise of one engine for fifteen months, and that order will not be completed until May, 1900.

"Now, gentlemen, engines are a necessity to us; we must have them. Therefore, we determined to send for tenders from two firms in America, one the Baldwin and the other Schenectady Works, and we received offers from them. In one instance the delivery was to be in ten weeks from the time that they received all the drawings and other data, and, in the other case, shipment from America in four months,—ten engines from each,—so that

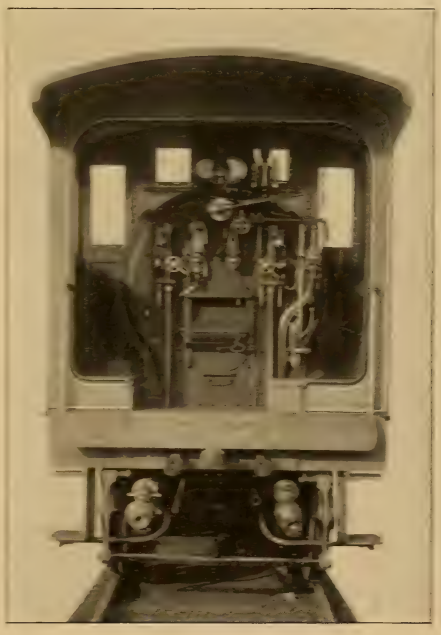
ONE OF THE MIDLAND ENGINES BUILT BY THE SCHENECTADY LOCOMOTIVE WORKS, SCHENECTADY, N. Y.

you see while we cannot get an engine promised in England in fifteen months, we can get twenty engines from America in four. I do not think we require further justification, and, thinking so, we have doubled the order to one of these firms.

"The engines which we have ordered will be of what is known in America as the Mogul type. They will be essentially American engines, but with certain modifications and alterations which our locomotive superintendent has thought necessary. These engines are of the same power as our own, and it will be very interesting to us, and to all Englishmen, I think, to see them running side by side with our own."

Since the chairman made that speech forty more engines have been ordered in England and ten more in America, making a total of two hundred and ten on order in England and forty in America at the present time. When these are all delivered, the Midland Railway Company will have 2780 engines. The question arises, How is it that American builders can supply locomotives so much more rapidly than British ones? It is true that the master mechanics in America, like their brethren, the locomotive superintendents in Great Britain, follow their own bent and identify themselves with the engines on the railroads where they are in authority, so that there is no end of variations in design and dimensions; but there are a few standard types, such as the Consolidation, Mogul, American, and Atlantic, used more or less throughout the States, and, in fact, all over the world, and if these are ordered pure and simple, or with but little alteration in the details, they can be had at remarkably short notice.

A vast amount of ingenuity has been expended by Americans in inventing and perfecting tools and machinery to execute work with the utmost despatch.



AN END VIEW

and whenever trade is brisk the factories are kept in full operation continuously with night and day shifts, and it is stated that the men (nearly all on piecework) work harder, as a rule, than they do in Great Britain, earning more money. Then, again, the American builders go in for less showy locomotives than we have grown accustomed to in England. They are satisfied with what is good enough, and do not expend time and labour on more highly finished workmanship than they think is requisite for all practical purposes.

The Baldwin Locomotive Works at Philadelphia, where thirty out of the dynamos furnish power for various machines and cranes and for lighting. The consumption of iron is about 2000 net tons per week, and of other materials, 100 tons per day, approximately.

Since the works were established in 1831, nearly 17,000 locomotives have been turned out, and in one year, 1890, no less than 946 were built, or, on an average, about three per day. By the system of manufacture employed, all important parts are accurately made to gauges and templets, and are, therefore, interchangeable throughout any number of locomotives of the same class. Any parts needed for repairs can be supplied

ONE OF THE MIDLAND ENGINES BUILT BY THE BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA

forty engines for the Midland Company are being constructed, are of colossal size, and the Schenectady Works, at Schenectady, New York, from which the remainder are to be supplied, are also very extensive. The Baldwin Works comprise twenty-eight buildings, covering an area of sixteen acres. The number of men employed is over 6000, and many of the principal departments run continuously day and night. Ten hours constitute a day's work as regards payment. The machinery is driven by engines with an aggregate of 5000 horse-power. The whole place is lighted by electricity, and seventeen

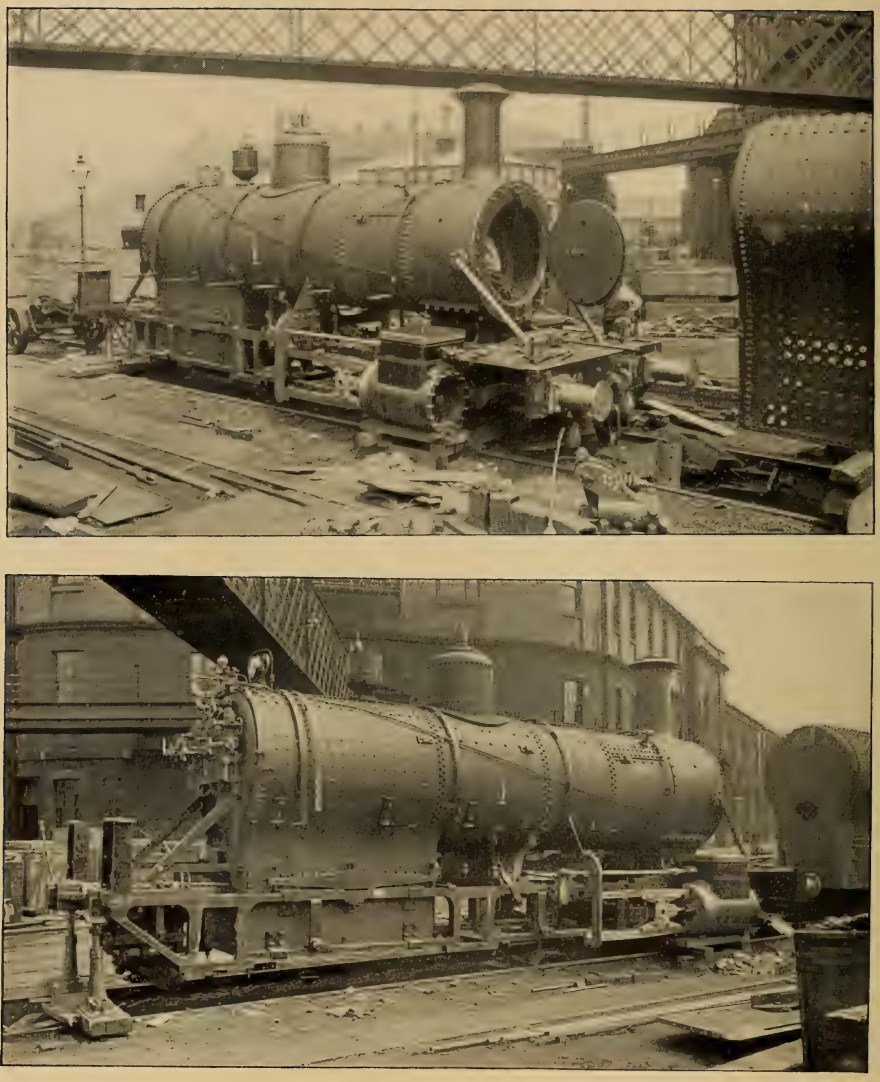
either with the locomotive or whenever subsequently required, so that the cost of repairs is reduced to a minimum and maintenance is attended with the least possible inconvenience and delay.

In the books of the Baldwin Company each type of engine has a distinctive number; it is only necessary to give that number, describing the part, and it can be supplied from the works without delay, and is guaranteed to fit in its place. Tables are furnished giving the hauling capacity of the various types of locomotives, their weight, and the principal dimensions, so that a selection can readily be made of the pattern of engine best

A FIRE-BOX END VIEW

suited for any class of traffic, or to meet the requirements of any railway of which the gradients, curves, and gauge are known. As an instance of the speed with which work can be executed by this firm, it is worth noting that an order was given on December 16, 1877, for forty Mogul locomotives for two Russian railways. The first of the forty was erected and tried under steam on January 5, 1878, three weeks after the receipt of the order, and was finished, ready to dismantle, and pack for shipment, one week later. The last engine was completed on February 13. The forty engines were thus constructed in about eight weeks, besides twenty-eight additional engines on other orders built in the works wholly or partially and shipped during the same period. No wonder the Americans have gained a reputation for smartness.

After the Mogul engines for the Midland Company had been erected, they



CONSTRUCTION VIEWS. THE ENGINES HALF FINISHED

were tested by jacking them up and running them in steam at the builders' works. They were then taken to pieces again and packed in wooden boxes ready for shipment. The principal parts of each engine are packed in separate boxes, marked clearly on the outside with distinctive letters and numbers corresponding to those on the consignment notes, so that, on arrival, the agents of the firm know, before they open them, the contents of each case and to what engine they belong; the weight of every article is also shown on the box. About twenty-four boxes were required for each engine. In addition, there were twenty-four other cases holding a miscellaneous assortment of fittings to be used on all the engines indiscriminately. The cases varied considerably in size and weight; the one with the boiler was 20 feet × 10 feet × 5 feet, and weighed about 14 tons, while the smallest box was 5 feet

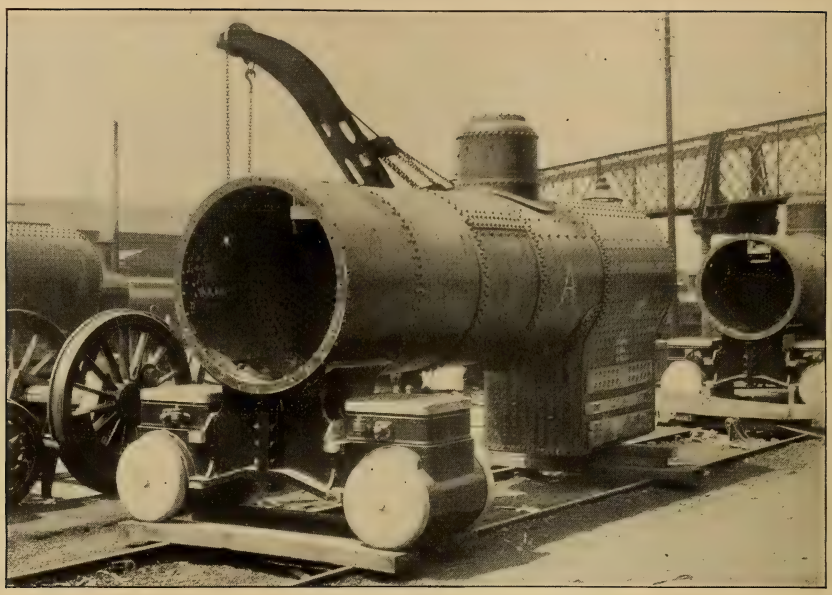
× 2 feet × 1 foot, and weighed 350 pounds.

The first ten engines, shipped at New York, came via the ship canal to Manchester, where they were put on the rails in Midland trucks. On arrival at Derby the engineers sent over by the Baldwin Works, with the aid of a steam and a hand crane, jacks, and ordinary lifting tackle, unloaded the trucks. Two sidings in the Midland Company's yard were set apart for the erection of the engines. The boilers, already tubed and mounted, and the cylinders, bolted together, were first placed on wooden packings across the rails and bolted to each other. The various parts of each engine were then deposited on the ground around the boiler belonging to it, so as to be within easy reach of the erectors. A few fitter's benches were hastily constructed and rough-and-ready hot water troughs provided for removing the grease and beeswax with which all bright work is coated to prevent its rusting in transit.

The boilers and cylinders being already in position, the longitudinal bar-frames are bolted to the cylinders and fixed inside the expansion brackets on either side of the fire-box. A heavy cast iron drag-plate is next secured to the frames behind the fire-box. The top of the drag-plate serves as the foot-plate, and on the under side the steam brake cylinder is bolted. The work of putting up the valve motion, fixing the steam and exhaust pipes, the smoke-box door, chimney, sand-box, and the fittings on the front of the fire-box and elsewhere is carried on simultaneously. The engine is then lifted by jacks and packed up while the wheels are run under. It is now ready for the coupling up of the eccentrics, connecting rods and outside rods. The foot-plating, wheel splashers, brake apparatus, cab, etc., having been added, and the boiler lagged and sheeted, the engine is finished in every respect.

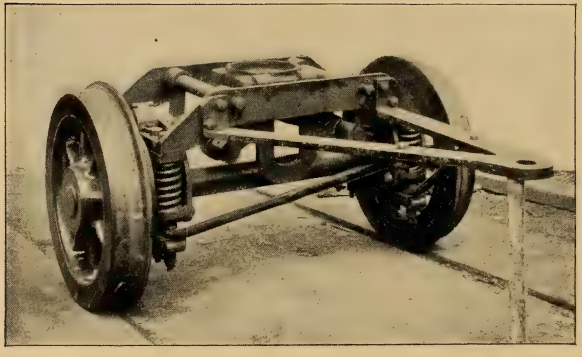
In the meantime, other men have been engaged on the tenders. The two bogie-trucks are placed on the rails, the tender frames are dropped on to them, and the tanks are lowered on to the frames. After that it takes but a short time to fit up the brake apparatus and feed pipes. The engine and tender are then coupled together, steam is got up, and a trial trip is made. The boilers

ONE OF THE ENGINES NEAR COMPLETION



ONE OF THE BOILERS WITH CYLINDERS ATTACHED

are clothed with magnesia sectional lagging,—a white solid substance, exceedingly light in weight, but very tough. It is supplied in blocks about 2 feet long and 6 inches wide, but varying in thickness to meet the inequalities on the outer surface of the boiler, due to the overlapping joints of the plates and to the taper of the telescopic rings which form the boiler barrel. The magensia blocks can be cut, like wood, to any shape required with an ordinary saw.



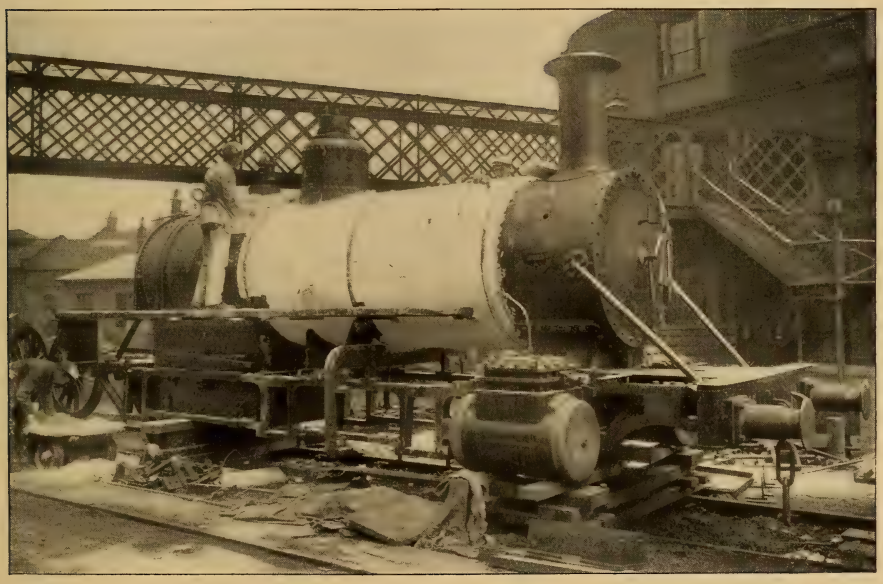
A PONY TRUCK

The operation of lagging a boiler is as follows:—Thin iron wire is wound round the boiler barrel so as to form rings at intervals along its entire length. Commencing immediately under the centre of the boiler the blocks of magnesia lagging are applied one after another and fastened to the wire rings and to each other by little wire hooks of special form. When the whole surface of the boiler is clothed with these magnesia blocks, abutting closely against one another, they are still further secured by steel tape bands drawn tightly around them. The lagging is then covered with smooth steel sheets painted the orthodox Midland colour. Six men,—three working on each side,—will cover a boiler with the magnesia blocks in about four or five hours.

The Baldwin Mogul engines supplied to the Midland Railway Company have outside cylinders, single expansion, with three pairs of driving wheels coupled together, and a two-wheeled swivelling pony-truck in front. The tenders run on two four-

wheeled bogie trucks. In general appearance the engines are not much unlike ordinary British engines, but the British school boys who have been so anxiously on the lookout for them will seek in vain for the bell-mouthed smokestack, the cow-catcher, and the huge lamp in front, which they have always regarded as the leading features of an American locomotive. They are conspicuous by their absence, for the simple reason that they are not required. In Great Britain wood is not used as fuel for locomotives, the cows are fenced off from the railway, and we have not to light up street level crossings by the aid of lamps carried on the engines.

Notwithstanding these important omissions, however, the construction of the American engines differs widely from the British. In some respects it was specially stipulated that the Midland practice should be adhered to in the engines supplied to the company. For instance, the inside fire-box and tubes were to be of copper instead of steel, and the wheels, injectors, steam-sanding apparatus, water gauges, and smoke-box doors were to be of Midland design and fitted with the combined steam and vacuum brake used on the Midland Railway; but with these exceptions it is difficult to find any similarity between the Moguls and our own engines. The frames, instead of being made of steel plates, one inch thick and eighteen inches deep, or thereabouts, with chilled iron axle guards bolted to them, are the bar frames so extensively used in America. They are formed of two longitudinal framed structures, one on each side of the engine, connected and stiffened by transverse bars and plates. Each structure is in three pieces. The main frame has an upper and lower member joined together by axle guards which are forged solid with it. In front are two single bars, bolted and keyed to the main frame, and to them the cylinders are fastened. These extend beyond the smoke-box and carry the front buffer beam and draw gear and support the swivel of the pony-truck. The bars of the frames are of hammered iron, 4 inches × 3½ or 3 inches. Cast iron gibs and wedges are provided to take up the wear of the axle-boxes.



PUTTING ON THE LAGGING

A distinguishing feature of the Mogul type of engines is the pony-truck which carries some of the weight at the leading end and serves to guide and steady the engine when passing over sharp curves. It is an ingenious device, with a swing bolster on which the central pivot rests, and spiral springs supporting the truck on the axle-boxes. The truck is connected to a triangular frame radiating from a vertical pin in advance of the leading coupled wheels, by which means the twist of the pony truck is kept within bounds.

As a rule, the weight of a locomotive built for British railways is so distributed over the axles that each spring bears its own weight unaided. The American practice is to link the springs on each side of the engine with each other by intermediate levers, so that if when running over a bad bit of road any extraordinary weight is suddenly thrown on one pair of springs, part of the burden is transmitted to the springs of the neighbouring wheel which helps to support it. In the case of the Moguls the weight between the driving and trailing coupled wheels and between the leading coupled and the pony-truck wheels is thus equallised.

The load at the front end of the engine is applied to the pony truck and to the leading coupled wheels through the fulcrum of a strong equilibrating lever. The front end of this lever is suspended from the centre-pin bolt of the pony truck and the back end from a cross-bar connecting the front spring links of the leading coupled wheels. The fulcrum is a pin through a stiff hanging bracket fixed on the centre line of the engine, between the cylinders.

The boiler, besides being firmly bolted to the cylinders, is attached to the guide-yoke carrying the back ends of the slide-bars and to a cross-stay intermediate between the guide-yoke and the fire-box. To allow for the expansion and contraction of the boiler, flexible plates, ⅜ inch thick, are introduced between the boiler and the guide-yoke and cross-stay. These plates are set at an angle, so that when the boiler is cold they bear slightly at the top side where they are joined to the boiler barrel, in the direction of the cylinders, but when the boiler is in steam and elongates by expansion they assume their natural vertical position. It is unusual in this country to have any connection between the boiler and frame excepting at the smoke-box and fire-box. No doubt the object of the American engineers in introducing the two additional supports is to distribute the weight of the boiler more regularly throughout the frames.

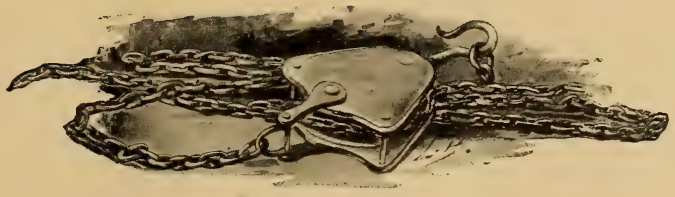
Some British engineers have criticised the lightness of the valve motion, but this is accounted for by the fact that balanced valves are used, which relieve the strain on the working parts. The valves of the Moguls are cast iron, placed at the top of the cylinders. Cast iron bars, fitted in grooves at the back of the valves, are held up to the steam chest cover by springs, making a steam tight joint and reducing the pressure on the valves. The cab on the American engines is much more roomy than those generally seen on British engines. It has two windows on each side, and a door with glass panels on either side in front. The driver can open these doors and pass along the foot-plate outside to oil the machinery while the engine is running. The sand-box on the top of the boiler, which has the appearance of a second dome, is fixed between the chimney and steam regulator dome. It holds a large quantity of sand, which, owing to its position, should be kept dry, but, being so high up, it is awkward to fill. In America the difficulty is overcome by erecting a high stage outside the running shed, to which the engines are taken to receive their supply of sand.

The lubrication of the valves and cylinders is effected, as in British engines, by sight-feed lubricators, and the journals of the axles are oiled from the top, or by pads on the under side dipping into reservoirs of oil below them. In Great Britain the slide bars, connecting rods, coupling rod bearings, and eccentrics are usually fitted with small cups fixed over the bearings, with a tube in the centre which passes down from the top of the cup to the shaft. The cup is

filled with oil, and a piece of worsted leads from the cup into the tube. By capillary attraction the oil is drawn up and drips down the tube on to the shaft. When out of use, the worsted trimming is withdrawn by a piece of wire, to which it is fastened, and waste of oil is thus prevented.

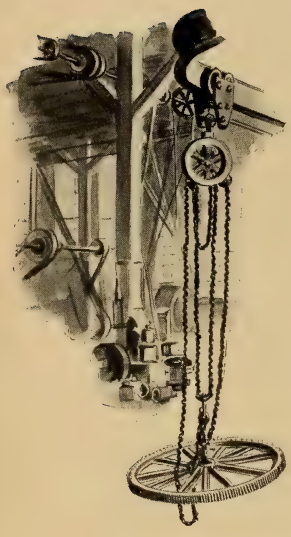
The American system is quite different. They use no trimmings. The orifice of the tube leading to the shaft forms a valve seat which is opened or closed by a set-screw with a tapered end. The set-screw, which works through the oil cup cover, has a very fine thread on its stem, and it is claimed that the flow of oil can be regulated to the greatest nicety by moving the screw a full turn or part of a turn, as required. By the aid of a finger on the top of the set-screw the drivers can judge to what extent the valve is open. They mark upon the edge of the oil cup the point to which the finger should be set to admit sufficient oil to the bearing. They usually have one mark for warm weather when the oil flows more freely, and another for cold weather when it runs sluggishly. In the oil cups of the slide-bars and piston rods the tube does not project above the bottom, and when the engine is not at work the set-screw is shut down to prevent the oil from running to waste. That is an unnecessary precaution in the case of the connecting, coupling, and eccentric rod oil cups, as in them the tube rises half way up the cup and the cups are filled only up to the level of the top of the tube. The motion of the cranks and eccentrics, as they revolve, jerks the oil against the stem of the set screw, down which it trickles into the tube and so finds its way to the journals.

Some of the American engines are now usefully employed working goods and coal traffic on the Midland Railway. They steam well, ride steadily, and haul good loads. It remains to be seen whether they will live as long, be as cheap to maintain, keep as free from failures, and prove as economical in the consumption of fuel as their British competitors.



INDUSTRIAL ORGANISATION

By Charles R. Flint



THE time has gone by when it is necessary to argue as to the right to exist of large aggregations of capital, for the purpose of industrial development. Every great movement in the world's progress has been opposed. Machinery has done more to benefit labour than all the acts of reformers and governments; yet originally the class most benefitted endeavoured to prevent its use.

The introduction of fast coaches in Great Britain was opposed to such an extent that petitions were presented to the King and Council, asking that no public coach be permitted to go more than thirty miles a day. Macaulay, in commenting on this historic fact, was prophetic when he wrote:—"We smile at these things. It is not impossible that our descendants, when they read the opposition offered by cupidity and prejudice to the improvements of the nineteenth century, may smile in their turn."

We are smiling in our turn, but, while combinations of wealth, of judgment, of experience and of executive ability are now generally recognised as a natural evolution in industrial development, all reflective men appreciate that, as mistakes have been made in the development of other great institutions, in the state and even in the church, so mistakes have been and will be made in the organisation and management of industrial enterprises; and at this time, when so many industrial corporations are being organised, it is important that we should compare views in order to minimise mistakes.

Fortunately the capitalisation of most of the industrial corporations which have recently been formed has been clearly defined, and, in the United States at least, has been based principally upon the earnings for the past five years. Business is active to-day and promises to be more so to-morrow. Profits are, and for the near future must continue to be, large. Add to this the advantages which will accrue from economies and other benefits secured by consolidation, and statements of profit will be rendered which will have a tendency to turn men's heads. The wise managers of large industrial corporations will charge off substantial amounts for depreciation and increase the surplus out of the unusual profits resulting from the increased demand and the decreased cost of production.

The danger point, in the writer's judgment, will be reached when new capitalisation is created, based upon the abnormally large earnings of this period of prosperity, and an undue advance in the quotations of existing securities takes place, in consequence of unexpectedly favourable statements of profits. The most successful American railroad companies,—combinations that have stood the test of time, the best examples of the advantages of aggregated wealth and intelligence,—have increased their reserves in good times, so as to be in a position to pay dividends in hard times.

At the close of the period of depression in the United States, from 1873 to 1878, the writer noticed that after some months of improvement many conservative men sold their securities, and the

public which purchased them made money because there was continued prosperity. After two years had elapsed there was a general feeling that prosperity had come to stay, that it had become permanent, and the men who had shaken their heads when the mercury in the financial thermometer was up only one-third of the way, departed from their conservative policy when it reached the top and argued that reactions such as had occurred in the past could not recur; that the political system had been perfected; that the wealth of the country had enormously increased; that the conditions of business activity were firmly established; that continuous economic development was inevitable,—and the names of those who invested at that time in the securities of the companies organised to parallel the New York Central Railroad represented the very pillars of conservatism. The result reminded me of the remark of Larry Jerome when the guide pointed out the Coliseum as "the greatest ruin in the world." "He evidently has never heard of Pacific Mail," said Jerome.

Industrial corporations, properly organised and well managed, because they can buy, manufacture and distribute more cheaply than their weaker and less able competitors, have an inevitable and a necessary advantage in the world's markets, and to the writer's mind they are sure to prosper. But he is equally certain that there will ultimately be a reaction from the present period of unusual business activity. The vital point at this time is to see that industrial corporations are organised and managed upon sound business principles and do not rush into over-production and thus help create the conditions of inflation which result in reaction and panic. What should be preached is the gospel of steadiness, and the new corporations are large enough and controllable enough to make for steadiness in a way that would have been impossible under the old conditions. They can, in case of need, be made the instruments of economic safety, just as the clearing houses have been made the instruments of financial stability.

The time when a check will be most needed will be at a later period, when favourable returns, resulting from the advantages of consolidation, plus the profits made in time of great prosperity, will cause industrial shares to be much more in fashion than they are to-day; when corporations will be looked upon by the speculative public as affording exceptional opportunities for stock market profits, when we reach the most inevitable period of inflation and boom, the result will be reaction and there will be danger of a crash.

In the organisation and management of industrial corporations there are certain dangers. One is jeopardising at the outset what is generally the most valuable asset of an industrial consolidation, namely, the good-will of the successful companies which are included in the consolidation. Each company, by years of honest dealing, has established relations of confidence with its customers, who are satisfied with its products and its methods. The danger comes when, upon the completion of the consolidation, some enthusiastic member of the newly formed executive committee, carried away by the theories of centralisation, and believing himself to be a Napoleon of Industry, attempts to centralise the business too rapidly and too dictatorily, destroying existing organisations, thereby injuring the good-will and endangering the whole. But experience has proved that in such cases you can rely upon the rare common sense of the hard-headed, practical men who have built up the industry. In the writer's judgment the greatest care should be taken, in organising new consolidations, to retain the services of such men. In several industrial consolidations in the organisation of which the writer has been associated he has urged, at the beginning, that the individuality and independence of the successful concerns shall be sustained and that the endeavour shall be to bring the standard of all up to that of the best, and not to centralise the business in such a way as to destroy the good-will.

Another disadvantage is that while

the financial interest of the individual entrusted with the local management of a sub-company or plant is as large in amount as before, his percentage of interest, owing to its being merged with other concerns, is very much less, and this inducement to exertion and economy is not as large as before.

In the export and import business we are able clearly to divide our business into departments, according to countries or staples, interesting each head in the department which he manages. Here the departments are independent.

In case of the consolidation of manufacturing corporations such an arrangement is very difficult, as there is likely to be a conflict of interest, owing to their interdependence. It is, therefore, undesirable to have any individual interested otherwise than in the common result.

An offset to the disadvantage of a reduced percentage of personal interest is accountability through accurate monthly comparisons of methods and results between the several plants. Managers are very ambitious to have their work compare favourably with that of others. The manufacturer thus has the advantage of comparisons with co-workers in the same line, every improvement is for the benefit of all, and manufacture and methods of distribution are brought to the highest state of efficiency and economy.

In studying the industrial situation, it seems to the writer well to take advantage of the experience in London, where the capitalisation of manufacturing concerns commenced in a large way before it was undertaken elsewhere. The amount of the capitalisation of industrials in Great Britain has aggregated £400,000,000. In many cases the capitalisation has consisted of putting in form for investment private businesses, instead of consolidating many companies into one large corporation, as has recently been done in the United States. The four hundred millions of British industrial securities have been, as a rule, most satisfactory investments and have averaged more profitably than most others. Their failure has been the exception.

In America, in addition to the advantages of putting private businesses into corporate form, the benefits of consolidated management are obtained, and the advantages of larger aggregations of capital and ability are thus secured.

If the writer were asked what these are, the answer would be difficult only because the list is so long. The following are the principal ones:—Raw material bought in large quantities is secured at a lower price; the specialisation of manufacture on a large scale in separate plants permits the fullest utilisation of special machinery and processes, thus decreasing cost; the standard of quality is raised and fixed; the number of styles is reduced, and the best standards are adopted; those plants which are best equipped and most advantageously situated are run continuously and in preference to those less favoured; in case of local strikes or fires the work goes on elsewhere, thus preventing serious loss; there is no multiplication of the means of distribution; a better force of salesmen takes the place of a large number; and the same is true of branch stores; terms and conditions of sale become more uniform, and credits through comparisons are more safely granted; the aggregate of stocks carried is greatly reduced, thus saving interest, insurance, storage and shop-wear; greater skill in management accrues to the benefit of the whole instead of a part; and large advantages are realised from comparative accounting and comparative administration.

Such are some of the advantages of consolidation. The grand result is a much lower market price, which accrues to the benefit of the consumers, both at home and abroad, and brings within reach, at the cheaper price, classes and qualities of goods which would otherwise be unobtainable by them. This is the great ultimate advantage, and if this were not sooner or later true, if the world at large did not ultimately reap the benefit, the other advantages would be as nothing.

The severest test of a business system

is in times of adversity. Under the conditions which prevailed before these large aggregations of wealth and intelligence, each manufacturer in times of depression rushed in to secure as much as possible of the reduced volume of business; the result was demoralisation. Under industrial combination, however, each concern obtains its fair share of the reduced volume of business at fair prices, and the contraction of business is conducted with the orderliness of a retreat of a well-disciplined army. Nothing in the past has more demoralised industries than over-production in times of prosperity and the scramble for a market in times of adversity, resulting in the cutting of prices to such an extent as to necessitate the reduction of wages and the manufacture of inferior goods. Such competition, instead of being the life of trade, is the death of trade, resulting in failures among jobbers, manufacturers and suppliers of raw material and even affecting that favoured class,—the bankers. In the long run the consumer is unfavourably affected by these conditions,—the goods he buys, though apparantly cheap, are inferior in quality, and he suffers, as all do, from disorganisation.

The writer has thus far given his views upon industrials from the standpoint of the corporate officer. But as a merchant,—and he has been such for a quarter of a century,—he would state that in the United States, for example, the change from two hundred million dollars excess of imports of manufactured goods in 1891, to sixty million dollars excess of exports during the past year, being a difference of two hundred and sixty million dollars in America's favour, has been principally owing to the development of economic manufacture through combination.

Over 80 per cent. of American exports of manufactured goods are being produced by such organisations while supplying the domestic demand, and to a very large extent manufacturing the implements and machinery, which in spite of high wages, have enabled American farmers to take advantage of the world's markets. The only way in which a nation can extend and hold its position in the world's markets for manufactured goods is to secure the advantages of highly developed special machinery, which is possible only through centralised manufacture and aggregated capital. Subsidy seekers claim that "trade follows the flag;" merchants know that trade follows the price and the flag follows the trade.

The wars of to-day are industrial wars; wealth is secured by production instead of by plunder; diplomats devote most of their time to studying trade conditions for the benefit of their home industries, and the most favoured treaties are those of reciprocity and commerce. We might as well expect to win the industrial battles of to-day by old methods, as to expect victory with old types of war vessels, manned by men who, as Joe Jefferson said, "had never had any rehearsals," as against those modern combinations of steel, electricity, powder, and dynamite, handled by men who had rehearsed.

In the centralisation of manufacture, the people at large are receiving great benefits, not only through lower prices for products, but by the opportunities offered for investment in the shares of industrial corporations. Incomes were being seriously impaired through the reduction of interest, and opportunities to invest in manufacturing properties were restricted; but now incomes can be increased through judicious investment in industrial shares. The writer is satisfied that in ten years from now there will be fifty times as many people interested in manufacturing investments as there were ten years ago. The trend of the times is centralisation of manufacture and wide distribution of the profits.

The wages of the workman can be sustained only by keeping in the lead in the development of labour-saving machinery through centralised manufacture. He must be placed and held in the position of an overseer of machines. To-day the productive capacity of the labour-saving implements and machinery of the United States, for instance, more than equals that of a population of 400,000,000 not using labour-saving

devices. It requires the intelligence of the educated workman to direct these labour-saving implements and machines. No other condition would justify the payment of overseer's wages which the American wage earner is receiving to-day.

Man power, under these conditions, has given place to machine power, and the man, instead of being a machine, a mere hand-worker, daily becomes more and more a brain-worker, and more and more a man. This more than any other single fact accounts for the increased prosperity of the American people, their larger leisure, larger liberty, and larger enjoyment of life.

It is a fact that the large industrial corporations require the best workmen and are to-day distributing in wages the largest sum of money so paid anywhere in the world, and at higher rates. Recently an American political leader of national importance is reported to have said that organising large industrial corporations was "good business, but bad politics." He was compelled to recognise that they were distinctly within the lines of economic progress and of benefit to the whole community. By "bad politics" he meant that the so-called "trust" issue, though in reality a false issue, could nevertheless be raised to create discontent in certain quarters.

The reply to this is, that such organisations, the basis of industrial prosperity, stand not only for good business, but good politics, and so long as they are well and successfully developed on conservative lines giving constant employment to the entire community, at advanced rates of wages, and lower prices for all articles consumed, and affording opportunities for increased profits to investors, it will be impossible for even the wildest demagogue to show that "good business" is "bad politics." The vital questions of to-day are economic ones, and the politicians would do well to study arithmetic.

Compare the condition of our people with that which prevailed before the aggregation of wealth and intelligence in the development of industries, when wealth was obtained by conquest, not by industry; when the masses had meat but once a week; when their houses were without chimneys and without windows, when their clothing and surroundings were filthy; when the death rate was double what it is to-day,—and you go back to a time when the nobility knew less of the world than the labouring man of to-day; when the present necessities of the masses were luxuries only for the rich; and you realise that the emancipation proclamations were written by Watt and Arkwright, Stephenson and Fulton, Franklin and Morse, and Bessemer and the great organisers who have applied their discoveries and distributed the benefits of their inventions to the whole world.

UNTRAMMELED SHIPBUILDING AND MARINE ENGINEERING DEVELOPMENT

By Joseph R. Oldham, N. A., M. E.

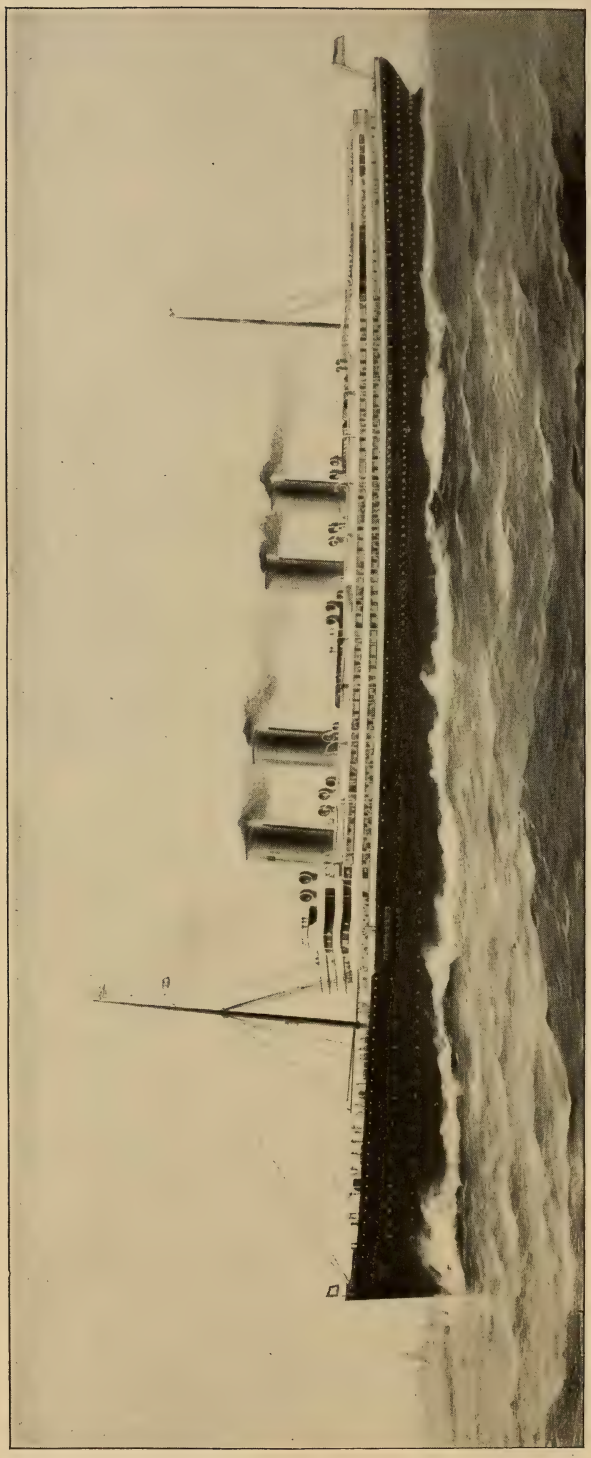
THE U. S. CRUSIER "MICHIGAN." BUILT AT PITTSBURGH IN 1843. THE OLDEST IRON STEAMSHIP IN THE WORLD

IF the transitory antiquary were diverted from the traditional birthplace of the marine engine to the shores of the new world in his efforts to discover the embryo mechanical structures of the early mechanicians, he would, no doubt, expect to find the oldest steam engine in America stored away in a locomotive shop or in the corner of an old saw-mill, and, if inclined to learn something about the oldest steamboats on the Great Lakes, he would naturally look for an American oak vessel, such as was engined by Robert Fulton in 1810 or thereabouts. In his quest for ancient iron steamers, he would probably look to the Clyde or to the Tyne, and there he could find one or two old ones, such as the *John Bowes*, built in 1852, and the *Bengal*, constructed a year later, or at least some authentic records of them.

President Henry F. Swan, in an address some time ago to the North East Coast Engineers and Shipbuilders of England, said that from their shipyard emanated, in 1844, an historic vessel, the *Q. E. D.*, which was the first screw collier ever built, and she was, moreover, the first vessel to be fitted with a complete double bottom for water ballast. The writer presumes that the *Q. E. D.* was an iron steamer, for it was the original firm of Charles Mitchell & Co., of which Mr. Swan was a partner, that built, a few years later, one of the oldest iron screw steamers afloat. The writer refers to the old steamer *Montague*, which for several years was operated under his superintendence.

But if the traveller at first referred to were to stop, on his way from New York to Cleveland, at the city of Erie, Pa., he could there see an iron steamer which was built at the same time as the first screw collier built in the old country, if not before, having been launched in 1843. To make this more realistic the writer would refer to a little American Civil War episode which resulted in the execution of one John Beale and the sinking of the steamers *Island Queen* and *Parsons*.

History states and eyewitnesses relate that in the year 1864 the American iron side-wheel steamer *Michigan* was on guard duty off Sandusky, Ohio, keeping watch over three thousand Confederate soldiers imprisoned on Johnsons' Island, and that good old steamer, then in her twentieth year, appears to have been in danger of capture by Major Cole



THE TWIN-SCREW 16000-TON STEAMSHIP "DEUTSCHLAND" NOW BEING BUILT FOR THE HAMBURG-AMERICAN LINE BY THE VULCAN WORKS, STETTIN, GERMANY.
LENGTH, 686 FEET. BEAM, 67 FEET. I. H. P., 35,000. AVERAGE SPEED, 23 KNOTS

and some Confederate passengers who were on board the *Parsons* and had actually taken forcible possession of her and subsequently taken the *Island Queen*, thus forming a little fleet with which they hoped to take the *Michigan* by duplicity or by strategy. The plot failed, hence the good old steamer is the most venerable side-wheeler in active service to-day.

Of the construction and condition of the *Michigan*, Lieutenant Commander C. P. Perkin, under date June 15, 1899, favoured the writer with the following interesting particulars:—

"The vessel was constructed at Pittsburgh, Pa., in 1841-43; the parts were transferred to Erie, put together and launched on December 5, 1843. The original machinery, with the exception of the boilers, is still in her and in good condition. The vessel is an iron paddle-wheel steamer of 685 tons displacement; length of keel, 156 feet 4 inches; length between perpendiculars, 162 feet 6 inches; breadth of beam, 27 feet; depth of hold, 12 feet 5½ inches.

"There are two inclined direct-acting engines. The paddle-wheels are of the usual radial kind, 21

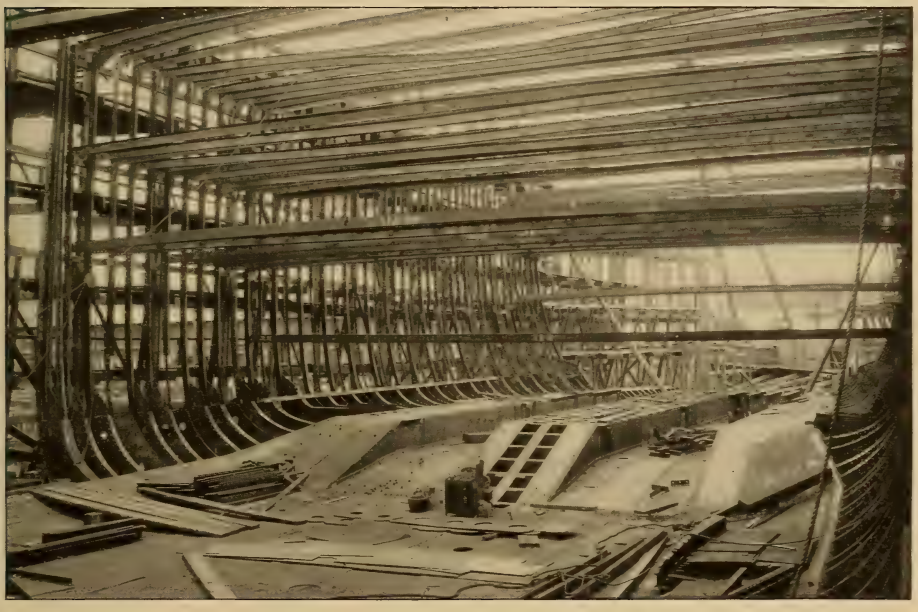
feet 6 inches diameter, with 16 paddles, 8 feet long by 1 foot 4 inches wide. There are two steel boilers of the flue and return fire-tube type, 9 feet 6 inches in diameter by 15 feet 2¾ inches in length over all; two furnaces in each boiler, 6 feet 6 inches by 3 feet 6 inches in diameter, and have each a grate surface of 22.75 square feet. The total grate surface is 91 square feet, and the heating surface, 1286 square feet. There is one smoke-pipe, 4 feet 4 inches in diameter, at a height of 42 feet 2 inches above the grates. Total weight of boilers, 47 tons.

"There are five heavy box keelsons, which run the whole length of the vessel. The distance from centre to centre of frames is 24 inches; frames of *T* iron, 4½ inches by 4 inches, with reverse bars, 4 inches by 2½ inches; keel plates, ⅝ inch thick; bottom and bilge plates, ⅜ inch thick; side plating and run aft, 5-16 inch thick; stem and stern posts, 6½ inches by 1½ inches; shear strake and plating carried up to the rail, ⅜ inch thick; deck beams are of *T* iron.

"This vessel has been in continuous service to the present time over 55 years, and is apparently as good for service as ever. During all these years of service no signs of weakness were exhibited.

"Her armament at the present time consists of six 6-pounders, two 10-pounder rapid-fire guns, and two machine guns. Of late years her principal occupation has been in the instruction of the United States naval militia at the different Lake ports, and surveying."

This is an age of standardisation or of limited variety in mechanical structures, at least. Standard scantlings for ships, however, have long been prescribed in Lloyds' and other register rules which are formed for vessels of standard proportions and dimensions. Then there are standard percentages prescribed for the elements and tests of steel and other metals, if the structure to which they belong is to be eligible for a "class." This standardisation is rapidly becoming more rigid and more extensive, and it seems to be undaunted either by huge proportions or the bold conceptions of the architect or engineer. As regards details of construction, channel bars can



A CONSTRUCTION VIEW OF THE "DEUTSCHLAND." THE FOUNDATIONS FOR THE TWIN-SCREW ENGINES

ANOTHER VIEW OF THE "DEUTSCHLAND" IN EARLY STAGES

be obtained only of standard depth, say of 6, 8, 12 or 15 inches, and as these bars are generally used for beams, frames and floors, it follows that from time to time the steel maker has a very considerable influence over the character of a structure.

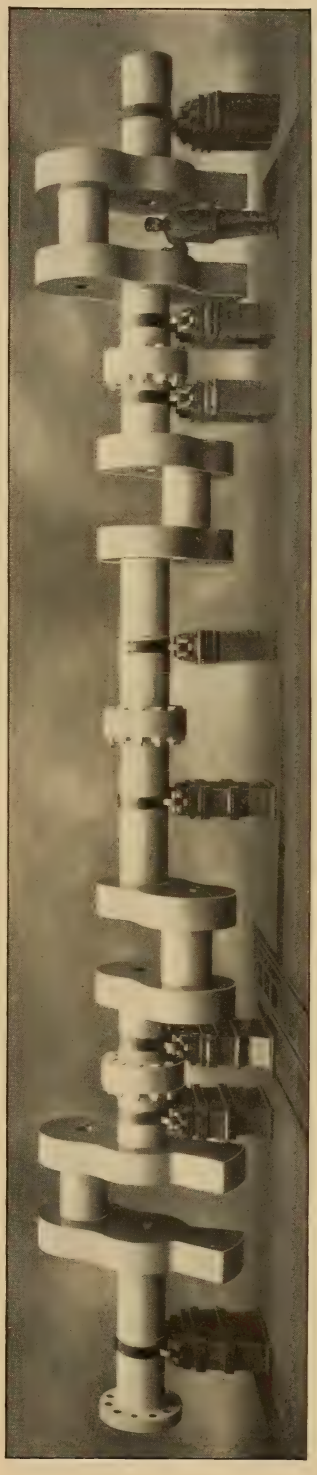
This standardisation, however, tends to great rapidity of production and largely reduces the cost of construction, whether it be a boiler or a bicycle, and that is a strong recommendation. In future years ordinary cargo steamers, at any rate, will, I believe, be built only to prescribed dimensions. Beams and floors will be made of standard length, of proper strength for the whole of the midship body, and even frames and web-frames may be made to standard depths; indeed, the whole of the hull may be

constructed ready for a purchaser, with provision for adding or deducting, say, 24 or 48 feet to or from the length, representing about 600 to 1200 tons, respectively, as may be required. Then, with regard to the engines, the determination of a standard type and of standard powers could be fixed without difficulty, and great expense would be avoided by a further development of the interchangeable system and reduplication of parts.

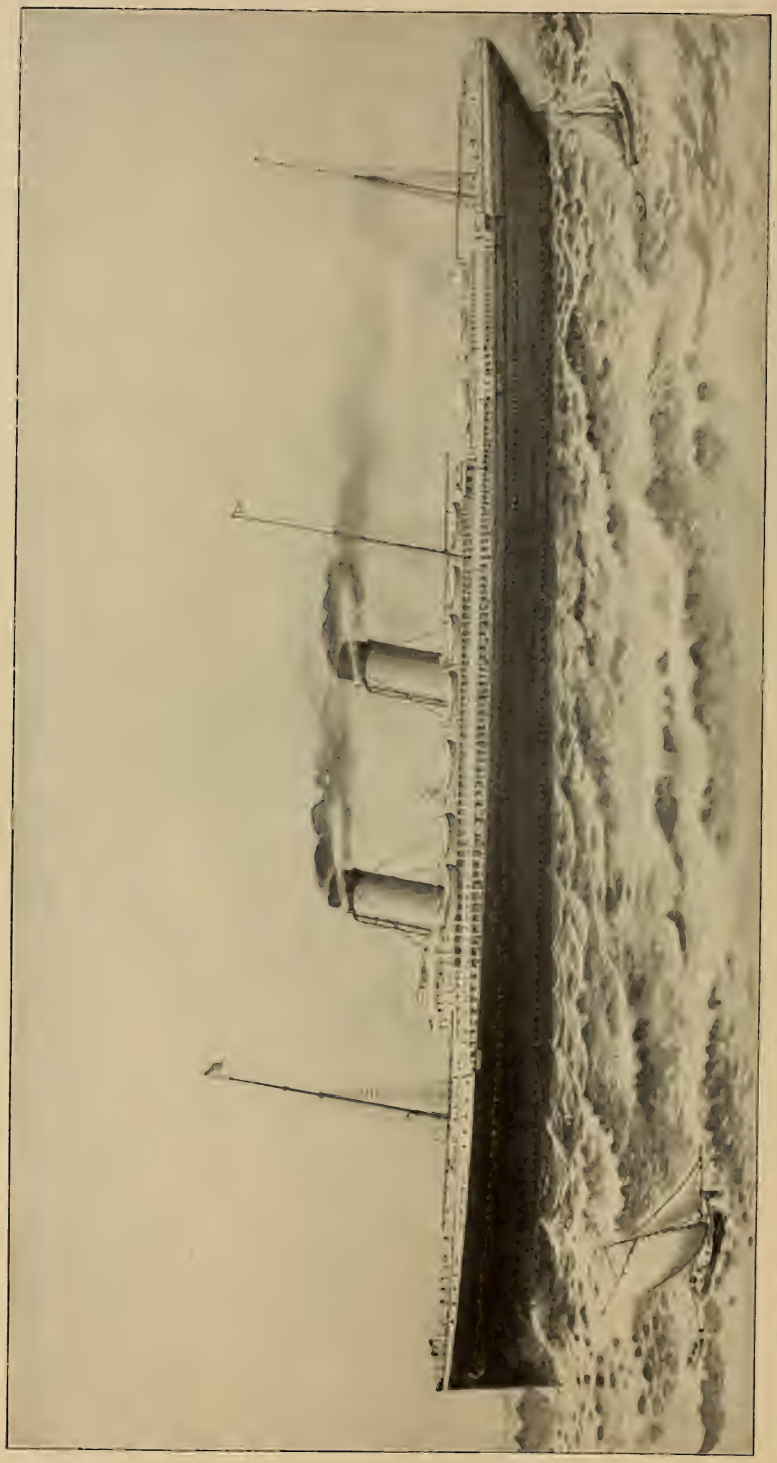
The unchangeable laws of nature will assist this evolution, for the resistance of the water will continue to vary with the square of the speed, and, as about 10 knots per hour (except for the North Atlantic trade) has, after many years of trial and error, been accepted by the prudent vessel owners as the most economical speed for ordinary dead-weight freight steamers, standard power boilers and engines might always be kept in stock, even though the latter be not erected till purchased.

Having made the drawings for the iron screw steamer *Delaware* in the year 1865, the writer can well remember her dimensions and peculiarities. She belonged to the same owners and was a sister ship of the *Propontis*, in which the first tri-compound engine was fitted. The *Delaware* was 326 feet long, 36 feet broad, and 26 feet deep,—large dimensions for those days. Indeed, there were few, if any, larger on the stocks at that time. But the largest shell plates on her hull were only 10½ feet long and 3½ feet broad, the gross weight of each plate being about 1100 pounds.

When I said the *Delaware* and *Propontis* were sister ships, I referred only to their hulls, the propelling power being quite different in the two vessels. The *Delaware* had large, square fire-box boilers and common condensing engines, consuming about 3 pounds of coal per I. H. P. per hour, while the *Propontis* had the first marine engines on the triple expansion principle. These engines were designed in 1874 by the late Dr. A. C. Kirk, and consisted mainly of three cylinders with their piston rods connected to three separate cranks. These were the prototype of the com-



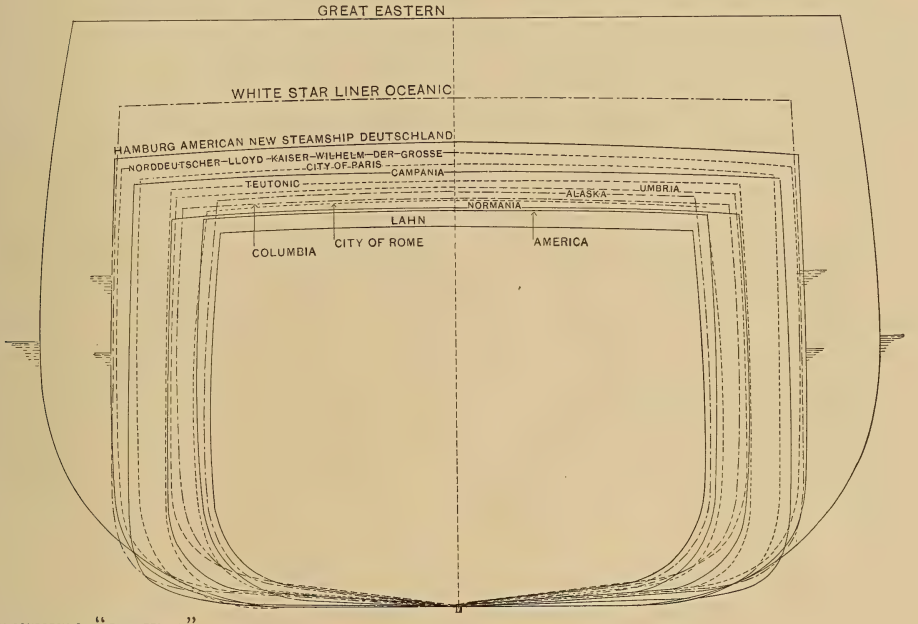
THE CRANKSHAFT OF THE "DEUTSCHLAND." DIAMETER, 25 INCHES. LENGTH, 58 FEET. WEIGHT, 22,330 LBS. MADE BY KRUPP, ESSEN, GERMANY



THE WHITE STAR LINE STEAMER "OCEANIC." THE LARGEST VESSEL AFLOAT. BUILT BY MESSRS. HARLAND & WOLFF, BELFAST. LENGTH, 704 FEET. BEAM, 68 FEET. DEPTH, 49 FEET. FULL LOAD DISPLACEMENT, 28,000 TONS

mon multiple-expansion engine of to-day. The principle involved in these engines, however, was patented by W. McNaught in 1845. Dr. Kirk's adaptation was highly meritorious and has done more than any other towards the advancement of screw propulsion since Wolf's invention in 1804, unless the invention of surface condensation by Samuel Hall in 1837 be excepted. But Wolf appears to have formed far too high an estimate of the gain to be derived by fitting two steam cylinders of cylinder direct without the intervention of the small high-pressure cylinder. Indeed, the object of the additional cylinders in the compound system is to reduce the temperature between the initial and terminal pressures by steps, and thus lessen the range of temperature in each cylinder. I am now referring to the economical use of the generating power and not to its mechanical application.

But to retrace my steps to the hull of the *Delaware!* The largest shell plates



BY COURTESY OF "ENGINEERING"

MIDSHIP SECTION OF REPRESENTATIVE ATLANTIC LINERS

different dimensions and expanding the steam separately in each engine, for, leaving out the question of condensation and re-evaporation in the cylinders, I may say that Wolf's high-pressure cylinder did not increase the power of the engine. It formed only a step in the work to be done, without adding to the power. It would lessen the range of temperatures of the cylinder walls to which the steam was exposed, but with a pressure of only 40 pounds that gain would hardly be appreciable.

A certain bulk of steam would develop the same power if admitted to the large

composing her structure were, as I have said, 10½ feet long, 3½ feet broad and ¾ inch thick. The average plates fitted to large American lake steamers to-day are five times as large and fully six times as heavy as those fitted on the *Delaware* thirty-five years ago. There was nothing peculiar about the mode of construction of that steamer. She was built in consonance with the prevailing practice of the day and was classed in two registries, and if surprise be expressed at the great number and small pieces commonly worked up into a ship at that date, I may explain that there were sev-

THE AMERICAN LAKE PASSENGER STEAMER "NORTH WEST," BUILT BY THE GLOBE IRON WORKS COMPANY, CLEVELAND, O. LENGTH, 388 FEET. BEAM, 44 FEET. TWIN-SCREW, QUADRUPLE EXPANSION ENGINES, 7000 H. P.

eral causes contributing to keep down the dimensions and to send up the number of units entering into such concrete structures as a steamship or a railroad bridge.

The human element in its physical capacity was one important factor of the problem. All the pieces of iron or wood had to be prepared and fitted by manual strength, without the aid of cranes or hoists, to any large extent at any rate; the "corner men" would not attempt to handle plates over certain dimensions, and the men were usually the masters of the situation. The riveters also considered it to their interest to retain or augment the great number of pieces, and their union usually gave them power to command. Then the iron mills had only small billets and rolls, and the classification societies certainly objected to broad plates, and certain associations discouraged long ones.

With regard to this, though a well-organised association, composed of highly respectable naval architects and

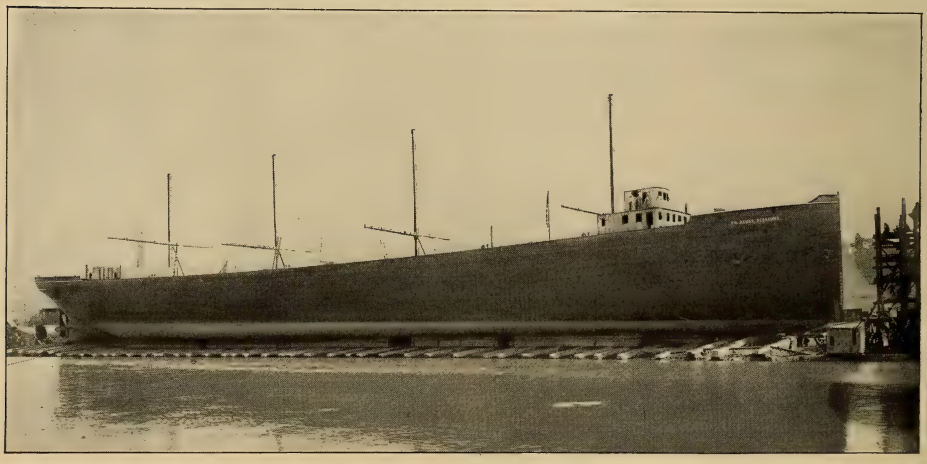
engineers, directed by a competent and thoroughly disinterested executive, may be a great safeguard to the maritime community of every class, its action is necessarily conservative, and, in the event of some unimportant projector like Fitch, or Symington, or Bell, or a non-influential shipbuilder proposing an innovation to the rules governing his "class," he would probably find it so hard to gain even a small concession that he would let it go "by the board" rather than lose more time over the matter. Even a very important firm had a most severe controversy, when the *Britannic*, of the White Star Line, was being designed, to obtain an increase of two inches in her frame spacing. On the Great Lakes the frame spacing has recently been increased two feet with great advantage, and with no loss of time or temper over the matter. But American shipbuilders are untrammeled. The writer would not say a word against the "book" of these days. It is an excellent work, and, when men create a good thing they are loath to allow innocent innovators to depart from rule, possibly, as they opine, to their ultimate ruin or everlasting professional disgrace. But time was, and that not long after the *Michigan* was built, when the classification books, —and I think there are about a dozen distinct books in existence,—were not so scientifically compiled or firmly complied with as some of them are today, and, during one or two busy years in shipbuilding errors of a purely theoretical nature passed uncorrected by the classification societies, and omissions of the most practical kind went

THE LAKE STEAMER "GLOBE" BEING LENGTHENED IN THE DRY DOCK

THE ANCHOR LINE STEAMER "CITY OF ROME." LENGTH, 560 FEET. BEAM, 52 FEET. I. H. P. 11,500

THE TWIN-SCREW STEAMER "KAISER FRIEDRICH." BUILT FOR THE NORTH GERMAN LLOYD S.S. CO., BY F. SCHICHAU, ELBING, GERMANY.
I. H. P., 28,000. DISPLACEMENT, 17,500 TONS

THE LAKE STEAMER "M. A. HANNA." BUILT BY THE GLOBE IRON WORKS CO., CLEVELAND, O., U. S. A.



THE LAKE STEAMER "SIR HENRY BESSEMER" PREVIOUS TO LAUNCHING. BUILT ALSO BY THE GLOBE IRON WORKS CO.

undetected, and dire was the sequel. It is a question whether the consequences of that spirited opposition would have been less disastrous if shipbuilders had been more accustomed to work to their own rules, with the whole responsibility resting upon themselves, thus being placed upon their commercial honour. But, judging from the conscientious work generally produced by shipbuilders on the Great Lakes of the United States, I incline to the belief that they would build as good ships without such minutely prescribed rules and figures, though such books may save a shipbuilder some trouble.

Then as to the advancement of naval architecture! It will surely be more rapid if responsible firms retain larger liberty when designing than is possible when governed by minute details of a binding character. The yacht *Anthracite*, built in 1876, was not eligible for machinery class with her boiler working at 400 pounds pressure, and though she and the Tyne ferry-boat, also fitted with

Perkins' patent machinery, were partial failures, it may be said that without such trial and error the present multiple expansion engine, with boilers working at 300 pounds pressure, and a horse power, indicated, per pound of coal consumed per hour, might still have been a result to be looked for in the distant future. Moreover, the pioneers in such advancement have usually been uninfluential individuals, not great and influential associations.

However, when structures reach enormous dimensions and cost, it is usual to assume that perfection is about attained and that it is the time when reduplication and standardisation flourish; and what more perfect specialty could there be than "class" rules, formulæ and tables prescribing every detail for a ship's construction, from a half-inch rivet, weighing a quarter of a pound, to an anchor weighing ten thousand pounds?

When venturing to criticise any feature or sphere of action of the great registry books of rules, I desire to disclaim the slightest inimical intentions in such action. Moreover, the books referred to have too strong a hold on the marine assurance situation to be displaced by anything less than a great commercial convulsion inimical to "class." I merely wish to state my conviction that the magnificent Lake steamers which have been constructed in the United States within the last half-dozen years would probably not have been so well adapted to the peculiarities associated with the cargo trade of these inland seas if the inventive genius and cautious enterprise of the several shipbuilders had been trammeled by classification restrictions, demanding compliance with preconceived rules and regulations affecting the smallest detail of construction. The fact should not be overlooked that the most capable experts of the great registries have been recruited from the shipbuilding yards, and it is questionable whether the most talented and enterprising men have yet been enlisted to prescribe diagrammatic rules and tables for the guidance of their quondam colleagues.

The great increase in dimensions, of ocean steamships, occurred when the *City of Berlin* came out in 1874. In a third of a century after the *New York* was launched, as will appear from the table below, the tonnage of the largest screw steamer, — omitting the *Great Eastern*,—had increased five-fold, the *Lucania* reaching 12,952 tons. If the capacity of the largest ocean steamers were to increase in like ratio during the next thirty-three years, the largest steamer would then be of 65,000 gross register tons. The corresponding dimensions,—if it be possible that my idea of length to breadth and breadth to depth will prevail in those days,—would be, length, 1100 feet; breadth, extreme, at upper deck, 120 feet; depth, 75 feet.

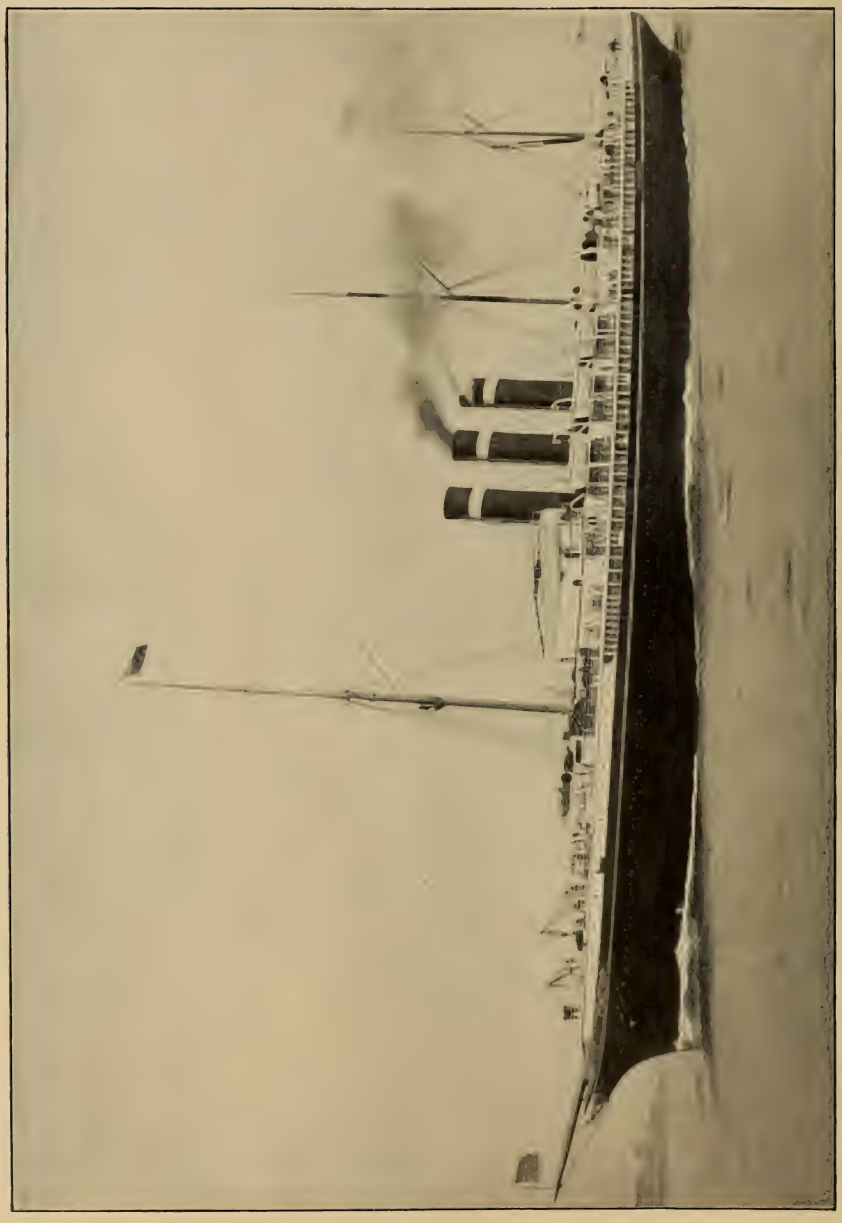
Since the iron screw steamer *Merchant* was built at Buffalo a little more than a third of a century ago, the capacity of the largest Lake steamers has

TYPICAL IRON AND STEEL STEAMERS.

Ocean Vessels.	Gross Tons.	Year Built.	American Lake Steamers.	Gross Tons.
		1843	Michigan	†600
O. E. D	700	1844		
Bengal	2,103	1853		
		1862	Merchant	†1,000
City of New York	3,523	1865		
		1868	Philadelphia	1,463
City of Berlin	5,491	1874		
City of Rome	8,144	1881		
		1882	Onoko	2,164
Paris	10,669	1889		
Lucania, etc	12,592	1893		
		1894	Globe	2,995
St. Louis & St. Paul	11,629	1895	Victory	3,774
		1895	North West	4,244
Kaiser Wilhelm der Grosse	14,349	1897		4,936
		1898	F. B. Morse	4,936
Oceanic	†19,000	1899	Douglass Houghton	†5,000

† Tonnage estimated.

Since the iron screw steamer *Merchant* was built at Buffalo a little more than a third of a century ago, the capacity of the largest Lake steamers has



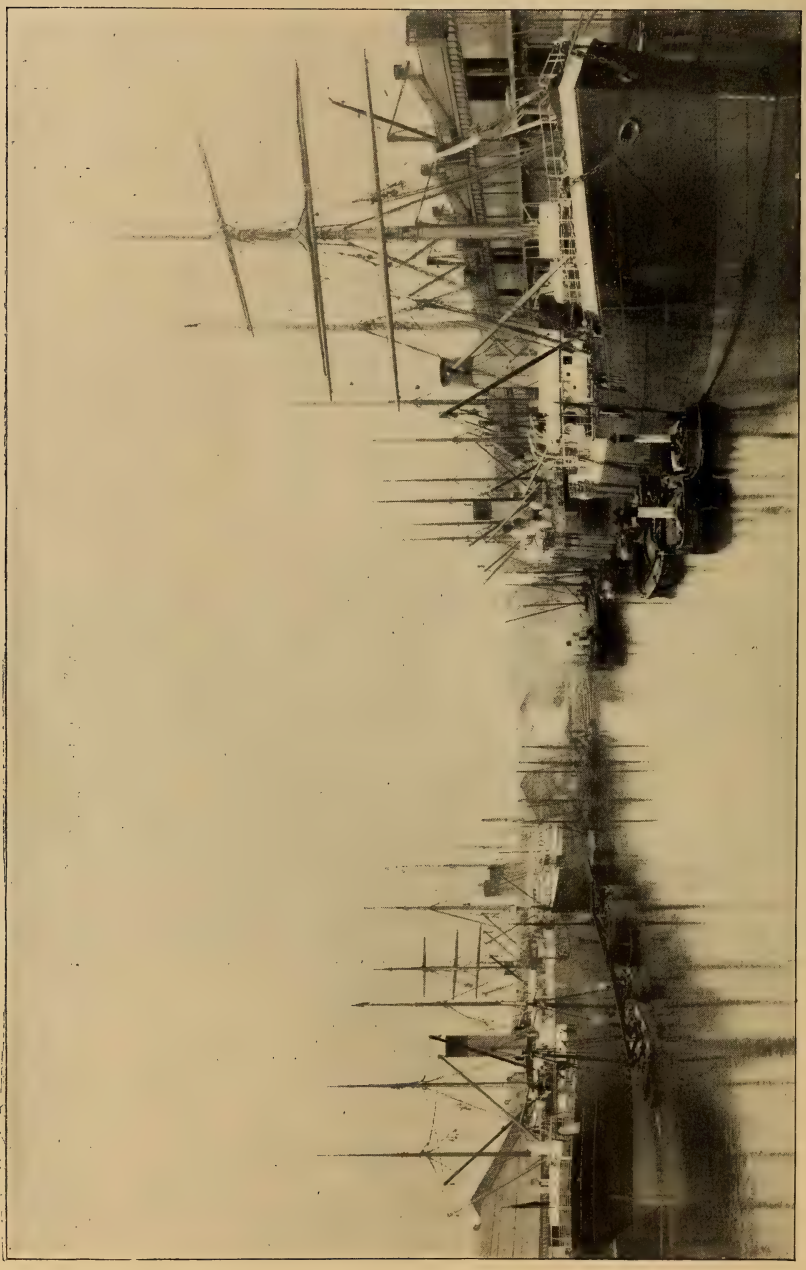
THE LATELY WRECKED AMERICAN LINE STEAMER "PARIS." LENGTH, 575 FEET. BEAM, 63 FEET. TWIN-SCREW, TRIPLE EXPANSION ENGINES, 20,000 HORSE-POWER

been increased sevenfold. Should the same ratio of advancement be maintained in the future, the Lake steamer of 1933 will be of 49,000 register tonnage, which corresponds to general dimensions of 1000′ × 100′ × 60′.

As to the speed of the future, I remember reading an article on mechanical impossibilities in *The Engineer*, of London, written about twenty-five years ago. It might have been by a second Dr. Lardner, for it was well written and possibly it was generally correct, but one operation, which was cited as impossible of accomplishment, was that of propelling a steamer at the rate of 25 miles an hour across the ocean. At that time the Atlantic had never been crossed by a screw steamer at so high a rate as 15 miles an hour, the *Scotia* being the fastest liner in those days, she having crossed the Atlantic at an average rate of 14⅓ knots. Steaming across the ocean at the rate of 25 miles an hour might, therefore, well have been looked upon at that date as impossible, but, to-day there are steamers which have reached that speed, and there are others in course of construction which may probably exceed that rate across the Atlantic.

Although, roughly speaking, the power required to propel a steamer varies with the cube of the speed, yet, before a third of the next century expires, another increase of at least 50 per cent. in ocean speed may safely be prophesied. How this is to be accomplished, it would be too hazardous to attempt to surmise; but I may point out how I think it will *not* be done, and that is by carrying and handling five thousand tons of bunker coals in a hull drawing nearly 50 feet of water. The model of the ocean mail steamer of the next century will probably be that of a

THE "VICTORY," ONE OF THE LARGEST CARGO BOATS ON THE GREAT AMERICAN LAKES. BUILT BY THE CHICAGO SHIPBUILDING CO., CHICAGO, ILL. LENGTH OVER ALL, 400 FEET. BEAM, 48 FEET. DEPTH, 28 FEET. TRIPLE EXPANSION ENGINES. CYLINDERS, 23, 38 AND 63 INCHES STROKE. I. H. P., 1800



CANADA DOCK, LIVERPOOL, SHOWING A NUMBER OF WHITE STAR LINE STEAMERS TIED UP

very much enlarged "destroyer" of great breadth and length and small draught of water forward.

Lighter and stronger materials will compose the structure, which may be moved by multiple propellers, possibly working in a tunnel, so that a number of wheels could be worked by separate shafts, actuated by rotary motors, as the sizes of screw shafts and engines even now under construction are perilously large; or the motive power may be produced by compressed air or gas. Then, the form of least resistance probably being discovered, the hull, broad and light in comparison with the augmented dimensions, will rise on top of the waves rather than pass through them. The rolling and pitching may be more severe than at present, but with improved cabins and a shortened voyage, the difference may not be noticed. The construction of a steamer of 65,000 tons will probably not trouble the constructors of the future nearly as much as did the building of the *Great Eastern* those of the past. There will be infinitely less labour, both mental and physical, than was required for the construction of a great ship in those days.

A modern American Lake steamer has only half the number of frames that were fitted in a steamer of like dimensions thirty-three years ago. The *Delaware* had 160 frames, and in those frames and beams there were five seams of rivets. To-day there are only two seams, so that in one case the framing represents $160 \times 5 = 800$ rows of rivets, and in the other $80 \times 2 = 160$ rows of rivets. The plates have been enlarged up to five times, so that if the *Delaware* had 44 strakes of plates in her total girth, and in each strake there were 30 butts, we get 1320 plates. The modern Lake steamer of the same tonnage has 28 strakes encircling her and has only about ten butts in each strake, so that there are only $28 \times 10 = 280$ plates. The saving of labour within the shipyard is thus represented by 640 seams of rivets in connection with frames and beams, and by the riveting of about 1000 plates, including the shell, deck and upper bottom. This does not show the whole saving of labour in connection with the building of a modern steamer, as compared with former practice, by any means. It is merely the most prominent feature of modern economy in ship construction.

Now the question presents itself thus:—If in thirty-three years the number of pieces of metal entering into the construction of a ship's hull has been reduced by 80 per cent., and if the cost has been reduced from about 10 cents to 3½ cents per pound, where are the probable mechanical or commercial obstacles to the economical building of ships in the future, of such proportions as above referred to?

The writer ventures to say that before all the new ships of to-day are worn out, plates 100 feet in length and weighing twenty tons will be as easily made and handled as plates of 30 feet in length are to-day. A 20-ton weight can be as easily placed in position by a 20-ton crane as a 3-ton weight by a 3-ton crane. Moreover, it is possible that riveted butts may then be things of the past, and the plates will be placed on the hull direct from the mill without a second handling. The writer remembers the time when boilermakers said they could not weld steel, but to-day a great deal of such welding is practiced, and boiler furnaces which used to be made in two or four pieces are now made in one piece. Small boats also are now made out of one steel plate. This is all exemplary of modern mechanical advancement.

Engine bed plates, which were often made in two or three pieces, are now in one solid casting. A word about this! There are many engineers who advocate making a casting in several pieces, so as to be prepared for easier repairing in case of fracture, and some object to boiler shell plates being made in one piece, as the solid plate will not permit of expansion and contraction to as full an extent as an assemblage of plates. But, in the writer's experience, the natural forces pay due respect to the big plates without seam, and to the big castings without joints, for they appear to stand the severe strains set up by heat

and cold as well as the small plates do, and they have fewer joints requiring attention.

As regards large castings, Mr. George Clark, the eminent engineer, of Southwick, often told the writer that if he could make a reliable casting, he would make the bed plate, condenser, and columns all in one solid piece. On the Great Lakes there has been a movement in that direction, for Mr. Newman, of the Globe Iron Works Company, of Cleveland, Ohio, makes his bed plates all in one piece, but he is allowed a free hand.

From this it may appear that the tendency is to make the great steel steamer of the future and her machinery of fewer parts than composed the small steamer of the past, and that progress along these lines will be the more rapid in the ratio that the "class" restraint is lessened. Just as commerce, to be successful with the nineteenth century competition, should be free, so large, systematised and well-organised shipbuilding and engineering establishments should be unfettered by vexatious government or corporate control, except to a very general extent. The writer's ideas, roughly expressed, of the lines of advancement of shipbuilding and engineering may be altogether wrong. But of two things he feels confident, viz., that we have almost reached the limit of draught of water, for though, considering two deep-draught vessels, it be perfectly true that the deeper of the two will be propelled by less power per ton displacement, it is, nevertheless, a fact that a boat can be driven faster *over* the water than *through* the water, with a great weight of it every now and again weighing her down and pushing her back; and secondly, that we have almost reached the limit of power to be produced through the medium of coal.

IRON IN ORNAMENT

By Chester B. Albree, Mem. A. S. M. E.

IRON enters so largely into modern construction that the question of its proper applications from an æsthetic, as well as from an engineering point of view, is an important one. As knowledge in general is mainly derived from precedents and a proper selection of the good from the bad experiences of the past, it would seem best, in order to properly understand the subject, to see in what ways iron has been used, how it has been worked, and what its æsthetic treatment has been in decorative work. What is here given has, in large part, been taken from a paper originally presented to the Engineers' Society, of Western Pennsylvania. To this, however, important additions have been made by the writer for the present purpose.

Iron was known in the very distant past, early hieroglyphic records indicating its use in India, China and Western Asia at least one thousand years B. C. It was then considered almost on a par with the precious metals in value, as in the year 900 B. C. part of the treasure captured at Damascus by the Assyrians consisted of 5000 talents of iron. A Jewish talent was 113 pounds 10 ounces Troy.

In classic times its use was fairly common in the Roman and Grecian empires. In various museums of Europe are to be seen pieces of window guards, andirons, rings and shackles, lamps and other household utensils, as well as weapons and armour. In Fig. 1 are shown some sketches of antique iron work copied from I. Starkie Gardner's excellent book on "Iron Work," published by sanction of the South Kensington Museum, London, to which the writer is indebted for much information regarding the subject.

In the museum at Pompeii may be seen a great variety of objects of iron, recovered from the ruins. Notable among these are some small window frames, containing glass lights. As is well known, the art of making window glass practically became extinct for centuries after the destruction of that city, and to find, amid the wreck of that enlightened community, iron sash with glass lights, is indeed a reminder of the old saying, "There is nothing new under the sun," for to-day we find the same thing in use.

The manufacture of iron into weapons, offensive and defensive, has continued from the first. Fine specimens of helmets, shields, swords, spears and other weapons are found in many museums, and were it not for the unfortunate quality of iron to rust away, we would undoubtedly have many more, as we have of the articles in the more durable metals,—gold, silver and bronze.

During the Dark Ages the art of working iron nearly disappeared, and not until about the eighth century do we again find it coming into ordinary use. The Gauls, Goths, Britons and Norsemen, having large deposits of rich ores and quantities of wood for fuel, reclaimed the art, in order to provide themselves with weapons for the hunt and for their continual warfare with one another. It is not within the province of this paper to enter into a discussion of the history of iron metallurgy, but simply to note that in these early forges, out in the woods, they succeeded in

making quite pure blooms, at first entirely by hand manipulation, later by the aid of trip-hammers which better worked out the slag.

The product of these Catalan forges and bloomeries was usually in the form of rough bars or chunks, which had to be worked down on the smith's anvil to the desired shapes. The superior qualities of iron for other purposes than weapons were appreciated, and its employment for hinges, locks, chains, window guards, portcullis gates and various strong treasure chests, with elaborately decorated hinges, straps and locks found place in the castles, and we find, from the tenth century onward, the feeling for beauty increasing with the growth of wealth, and the skill of the smith keeping pace.

The smith of those days was generally a serf,—almost a slave to the reigning lord or baron. His time was his master's, and, as the noble robber barons controlled nearly all the wealth of the land, and were mightily proud of their picturesque strongholds, they would employ the smiths for months, or even years, on a single piece of work that would add beauty and strength to their domain. Hence we can understand better how such wonderful work as is shown in the illustrations given came into existence.

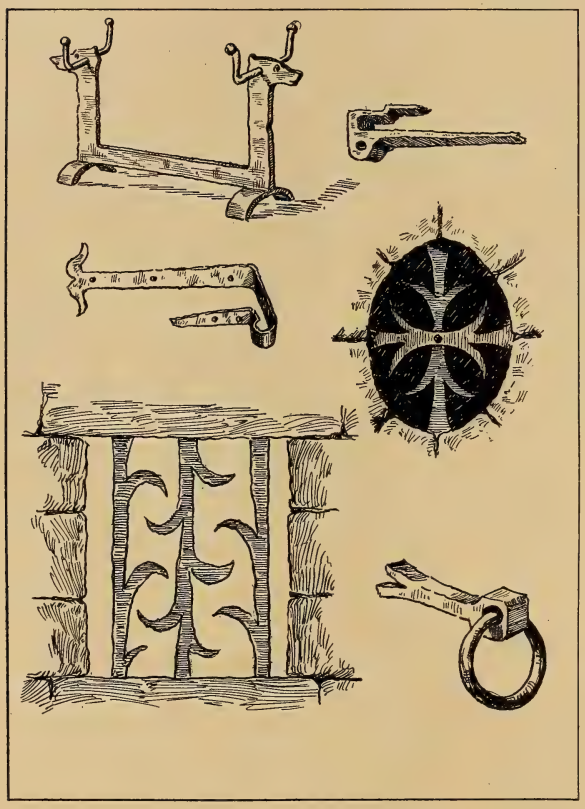


FIG. I.—ANCIENT ROMAN IRON WORK

Notice that the keys, locks, knockers and other small articles are really more like jewelers' work, in their wealth of repoussé and sculptured decoration, inlay and engraving, than like products of a smithy! The church vied with the barons in wealth, and spent enormous sums in the building of cathedrals and monastical establishments, and in most of them exist to-day wonderful grilles, shrines, altar railings and other features of iron, calling for bolder design and larger work than the "Schmiedeisen" or lock work of the castles. Notice the extreme difficulty encountered in the welding, interlacing, banding and decoration of some of these masterpieces! With all our modern appliances for rapidly and easily working iron we see no way to accomplish some of the results they attained, except by hand work, with time left out of the question.

utensils grew steadily as civilisation gradually replaced barbarism. Fig. 3 gives examples of this earlier work, which was meant for use and not for ornament. The continued progression of civilisation brought in its train the desire to beautify and adorn. Scrolls were added to the hinges; andirons were wrought into grotesque shapes;

The use of iron for grills, gates, and other fixtures, and for ecclesiastical pur-

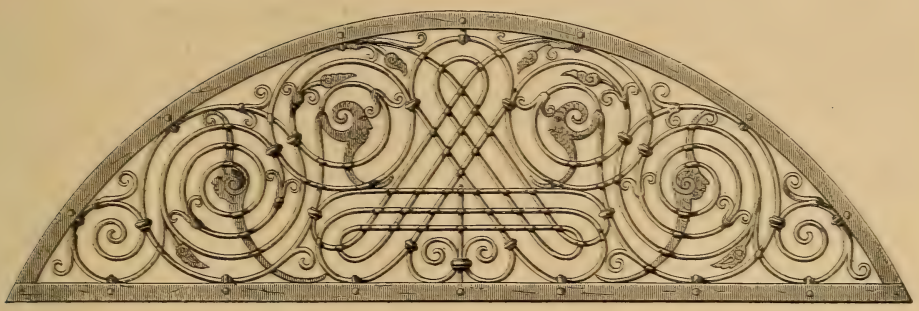


FIG. 2.—AUSTRIAN WORK OF THE SIXTEENTH CENTURY

poses generally, spread all over Europe, each country stamping its work with its own individuality. Noticeable among the different styles was the Austrian work, Fig. 2, in which interlaced round bars, in peculiar concentric forms, varied with scrolls, relieved by flat plate, leaf and griffin designs, often gilded or coloured, are very prominent. The general design is typically illustrated by the railing or guard around Maximilian's tomb, at Innspruck. The enclosure is made up of a number of panels, one of which is shown in Fig. 4, each differing in design and yet being in harmony with the rest. In Italy purer forms were used, the trefoil, quatrefoil and cinquefoil, combined with C and S-shaped scrolls, predominating. Leaf work was little used. A good example of Italian work is shown in Fig. 5. But to France we owe, perhaps, the finest examples of wrought iron work. The grace and beauty of design, pure and simple, with the correct use of repoussé work, and solid forged ornament, is typified in the renaissance work of the sixteenth and seventeenth centuries, a style well shown in Fig. 6. German work of this period, while showing wonderful technical skill, had become so replete with detailed and elaborate ornament, as to lose all its original character, as may be seen by inspection of the oval panel shown in Fig. 7. The French work is a delight to behold in its true expression of the æsthetic value of ornament rightly applied.

FIG. 3.—EARLY MEDIAEVAL WORK

In America, there was a period in which iron design was exceptionally

good, known as the Colonial period. It was, as regards architecture, an adaptation of classical lines to domestic and public buildings. It was conspicuous for its simplicity and pureness of general design, and of detailed decoration and easy adaptability to various classes of buildings. The development as regards iron work was along the line of straight vertical rods with panels at intervals, with simple scroll, circle and oval decorations often accompanied by friezes or bands of scroll work,—running in free lines, but with frequent repetition. A typical design is shown in Fig. 8. The style was good, and is to-day as popular, and deservedly so, as that of any of the regular schools.

About the end of the eighteenth century and the beginning of the nineteenth a new departure in the use of iron came in vogue. Cast iron, by reason of its cheapness, and the facility with which

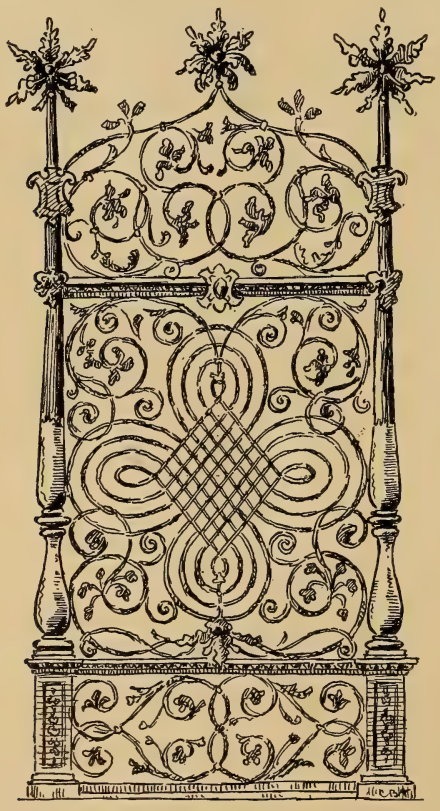


FIG. 4.—A PANEL FROM MAXIMILIAN'S TOMB RAILING

FIG. 5.—ITALIAN STYLE.

duplicate pieces, of apparently fine design, could be produced, became very common. Designers ran riot in their ideas, and many monstrosities, embodying a general jumble of styles, survive as reminders of the period. To gain the required strength, the cross sections were made heavy, the natural result being the production of cumbersome, awkward effects, as compared with those of wrought iron.

Still later, iron castings replaced wood and stone for many purposes, such as for girders, columns and lintels, and the so-called "iron buildings" naturally followed. The force of habit made the designers follow accepted architectural styles, and we find these structures made in the semblance of stone, for columns, arches, pediments, etc., even to the imitation of the mason's chisel marks. The light shell castings covered real girders and columns, at first also of cast iron, and later of rolled beams and shapes.

Such buildings represent an evolutionary stage, and, as such, can be tolerated; yet the true principle of design and decoration is to make things strong and pleasing by means of their own intrinsic qualities, and suited to their duty and environments, and not by any sham

veneer or other subterfuge, seeking to disguise the truth. Up to our own day, the evolution has progressed steadily, bringing as its latest development the modern steel-framed building, made possible by the wonderful achievements in iron and steel metallurgy, and the corresponding progression in knowledge of the theory and practice of engineering in its broadest sense.

To-day a modern American office building is a triumph of engineering skill from top to bottom. The foundations, involving pneumatic caisson work and intricate and exact calculations; the skeleton, designed and figured as carefully as a bridge; the fireproof floors and walls, the iron stairways, rapid elevators, electric lighting, sanitary plumbing and ventilating,—even the mail chute,—all give evidence of the evolution of the engineer. But have the architects done as well for the exteriors as have the engineers for the interiors of these buildings? This is a large question, involving many new and difficult points, which are gradually being solved. It was a new problem to design a fifteen or twenty-storied building and still hold to conventional ideas of architecture. That some city architects did not grasp the subject, is evident in many ways.

But the change is coming, and there are in existence to-day buildings on which the architect and the engineer have worked in harmony to produce a design fitting the new conditions with signal success. There are, however, numerous buildings in some places which, while undoubtedly strong and substantial and suited for their purpose, appear absurd to a thoughtful observer. As an illustration, there is a modern building in one American city, towering up to the clouds, having on the ground floor two store fronts, each about 40 feet wide, with a stone lintel with vertical joints, running from pier to pier. The only apparent supports in the 40-foot spans are some light cast iron columns or posts, forming the window and door divisions. Resting on each lintel are two brick columns about 4 feet wide, extending upwards many stories. If we were to really conceive of them as being sustained by the stone lintel, we would have to completely revolutionise all our theories of the supporting power of iron columns and stone lintels. Engineers know that the plate girders behind the lintels, resting on iron columns behind the stone piers, really support all this weight; yet it does not appear so. Is it good design to make this stone lintel appear to carry the load on it, when the most casual observer would know that it would fail with one-tenth of the load, if actually carried upon it?

FIG. 6.—FRENCH RENAISSANCE

There are other buildings in which the architects have successfully dealt with the problem, and while really supporting the structures by steel columns and framing, have given the impression of solidity, strength and beauty. Just how far we should follow precedent, in covering the bare columns with a facing of stone or brick, and in making imitation

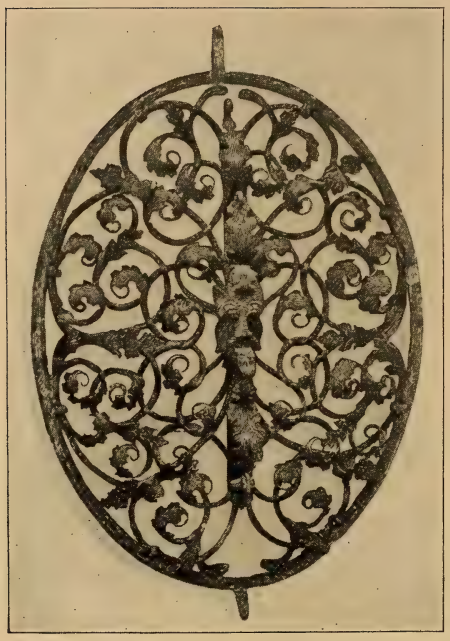


FIG. 7.—A SPECIMEN OF GERMAN WORK

arches, to give architectural effect, is a problem for the architects, and not the engineers, to solve. It is the result of the use of iron in construction for which we stand sponsors. We will let the architects work it out, aiding them all we can. But there is a class of structures, for whose design engineers are directly responsible,—bridges, viaducts, large roofs, iron buildings, and hosts of other work that have not been handled nearly so well as have been the office buildings by the architects. They are, as a rule, unsightly skeletons, justifiable only by reason of their utility.

That this condition is true is perhaps not wholly the engineer's fault, for he works for others, and in this age of fierce competition the tendency has been to eliminate from the design everything extraneous to the actual need. Architectural effect requires consideration from the start, and if a structure is designed without regard to it, subsequent attempts at decoration, by means of towers, finials, or floral embellishments simply tend to make the appearance more inharmonious. Artists tell their students continually that to succeed in art the first requisite is accurate drawing, and that no amount of painstaking shading and colouring will redeem a picture inaccurately drawn. This is true, and we might well apply it in engineering.

In this modern age, when knowledge is so much broader than formerly, it is impossible for any one man to be posted in all branches. In the engineering profession we are drawing the lines closer and closer, so that we have specialists for each line of work,—railroad engineers, electrical, mining, mechanical, hydraulic engineers,—each fitted and trained to his own business, and each, therefore, an expert in his field.

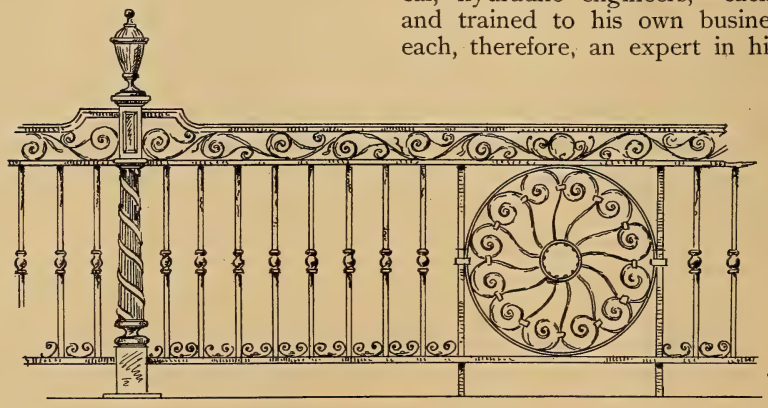


FIG. 8.—COLONIAL STYLE

When the electrical engineer needs an engine of certain specifications, he does not attempt to design it himself, but consults the mechanical engineer or

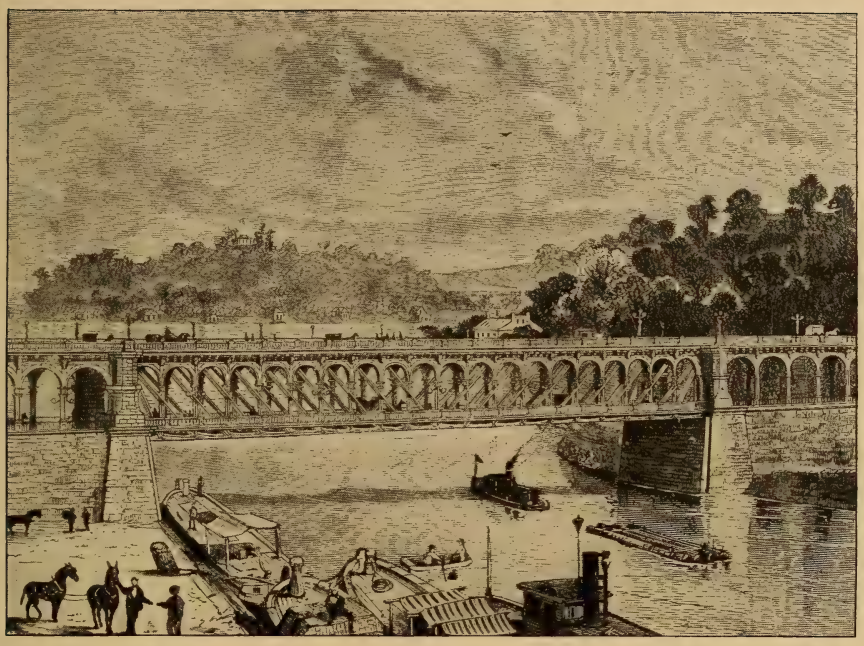


FIG. 9.—THE FAIRMOUNT BRIDGE AT PHILADELPHIA. A FAILURE FROM AN ARTISTIC STANDPOINT.

manufacturer to supply him. The mechanical engineer returns by asking the electrical engineer to furnish his works with an electric lighting or power plant. This is as it should be; but when it comes to designing a bridge or other structure, where the question of appearance is concerned, we say to ourselves, "We can design such a structure; we know what a bridge should be better than any one else; an architect would be of no possible use." So we build something that certainly answers the purpose, but only in rare cases does it have any merit from an æsthetic point of view. This is to be expected, for we have given our study and energy to the engineering problems, to the entire exclusion of æsthetic ideas, and we can no more suddenly, as if by inspiration, design a structure of appropriate and artistic beauty than we could paint a fine portrait or carve a group of statuary.

A notable example of failure, from the artistic standpoint, is the Fairmount bridge across the Schuylkill River in Philadelphia, leading to Fairmount Park. It is shown in Fig. 9. It is a deck bridge, the vertical struts being enclosed by a fancy column and base with arches of cast iron sprung from one to the other, supporting a roadway with massive cast iron railing and corbels, all made in imitation of cut-stone work. The bottoms of the struts are connected with the customary eye bars and the diagonal members cross between them, so that from a distance the lower chord almost disappears from sight, and we have the absurd effect of a great mass of masonry, — looking like an old Roman aqueduct, suspended high up in the air as if by magic. Nothing could be worse from an artistic point of view. While this is an extreme case, there are very many structures that can be justly criticised.

The obvious lesson is that for work that, by reason of its environment and purpose, should be a decorative feature, the engineer should work in perfect harmony with the architect, each modifying his ideas to best promote the design as a whole. The general scheme of the work should be mapped out, keeping the æsthetic side principally in mind, and making the engineering part contributory to the main end in view.

That such a course is possible is plainly in evidence in many European cities. In the beautiful railroad stations of Frankfort, Cologne, and Paris, for example, the buildings, train-sheds, elevated approaches, columns, and railings all harmonise with the general design, and yet, in themselves, are worthy of admiration separately. In Paris, across the River Seine, are bridges of considerable span that, instead of being blots on the landscape, add a greater charm to the river views of palace, church and castle that have made Paris famous the world over. To-day the new Alexander Bridge,—across the Seine, in Paris, almost completed,—is challenging the attention of architects and engineers the world over, as having been especially designed, at great cost, to meet æsthetic ideals.

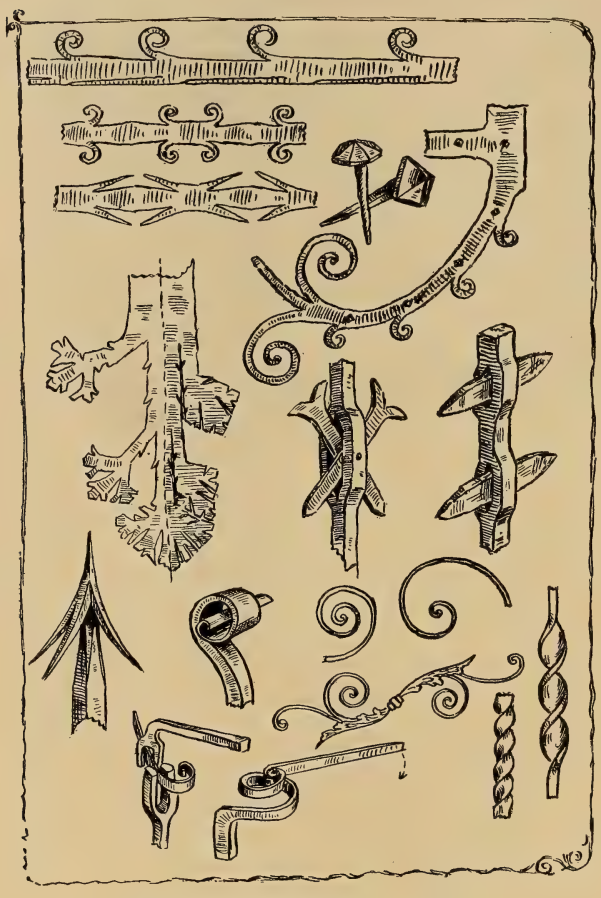


FIG. 10.—SOME EARLY WAYS AND MEANS

In mechanical engineering, some of the earlier machines show ill-advised attempts at decoration. In December, 1898, there was published in this magazine an article on machine design, well illustrated with pictures of lathes and planers, with architectural columns, panels, scrolls and flutings, entirely out of place on such tools. There were also given illustrations of modern machine tools, in which all attempts at decoration had been abandoned, and the outline designed solely for strength and convenience. That decoration and ornament, in the right place, are good, goes without saying, and it is equally true that decoration in the wrong place is bad. Let us, then, as engineers, use our efforts to further the advancement of true art and beauty in engineering structures, and let us acknowledge our lack of technical, true knowledge of the æsthetic part of designing, and leave that to those who are competent to deal with it, aiding them by our ability to carry out, as near as may be, their ideas! This plea for better design of engineering work is, perhaps, not strictly relevant to the subject of ornamental iron, yet it is really much more important to the engineering profession than the history or art of working iron.

A study of the methods employed by the mediæval smiths, and the wonderful effects they obtained, as contrasted with modern methods of producing ornamental iron by machinery from rolled or forged shapes, will be of some technical interest. Recalling the product of the early bloomeries and Catalan

forges as being rough bars or chunks, the mediæval smith was compelled to forge out by hand, on the anvil, the special shape he required. As a result, articles for use were paramount, and decoration was an after-thought. The first forms of window guards were plain squared bars, let into the stone, or having the ends flattened and nailed to the wood frames. Such forms are still used to-day. Perhaps the next step was to drift a hole in a bar, when hot, as they had no power punches or drill presses to aid them, and insert in the hole a round or square cross-bar, pointed at the ends, and calking it tight.

By making a bar a little wider and splitting it, similar to a feather, and then curling up the slivers, excellent scroll effects were produced without any welding. Many examples of this class of work, adapted to various purposes, are found. The sketches in Fig. 10 show clearly the process and results. This scheme was further carried out by forging out a sheet of metal, generally tapering towards the ends, and cutting it by hand chisels into various leaf or other forms, flat, and then bending or beating them to some preconceived design. The older German hinges show this very clearly. As the knowledge of the art advanced, true scroll-work grills were made, the scrolls being welded to one another, or to the main stems, or secured by small encircling bands of iron, sometimes merely wrapped around, and the ends butted, and in other cases, welded on. The welding required very quick work in handling heavy, awkward pieces, and yet holding the heat.

The number of combinations possible of simple C and S scrolls is without limit. Heavy, strong guards and gates for prisons and fortresses were made by interlacing the bars or by running one bar through a hole pierced by a drift in a cross-bar. The vertical bars or pickets often had sharp points, fantastically arranged. The most difficult guards to make consisted of bars alternately passed through each other. It may be seen from the sketch in Fig. 11 what tedious, careful work was required, with increased labour as the grills grew in size. In fact, it is hard to understand how some pieces ever were made.

The decoration of scroll work with acanthus and other conventional leaf forms, followed. The flat shape was cut from plate, beaten by repoussé work to the form required, and welded or otherwise secured to the grill. Such work calls for a high order of artistic feeling in the smith. Some followed designs made for them; others apparently made up the designs as they worked. Rosettes, flowers, faces, dragons,—in fact, all kinds of designs,—were wrought in iron, with such skill as to challenge attention with the best of work in more ductile or more easily worked materials. Beautiful examples of such work are to be seen all over the continent of Europe.

In the smaller pieces of work, such as hinges, locks, keys, and knockers, somewhat different methods are noticed. Plates, decorated with elaborately cut stencil work designs, often Gothic in style, were used in combination with repoussé and chiseled work. Such work can hardly be classed as blacksmith work, as may be judged from the

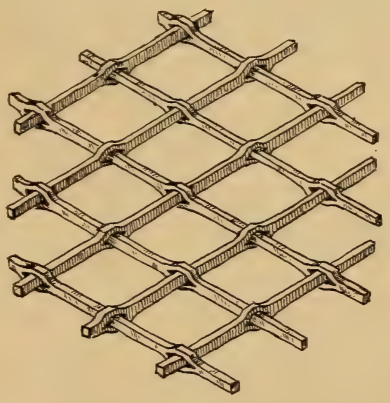


FIG. 11.—AN INTERLACED GUARD

examples shown in Figs. 12 and 13. It is the work of artists, and some of it may be classed with the masterpieces of Benvenuto Cellini, the jeweler-sculptor. Comparatively little work was riveted

together, and screws were almost unknown. Certain methods were followed, which were the forerunners of the modern drop forging processes. When numerous pieces of similar relief design were needed, a matrix was made from a carefully wrought original by impressing white-hot metal upon it, until a sharp intaglio was formed. Subsequent reversals of this made many exact duplicates of the original. It is probable that much of the relief work on the beautiful hinges of Notre Dame

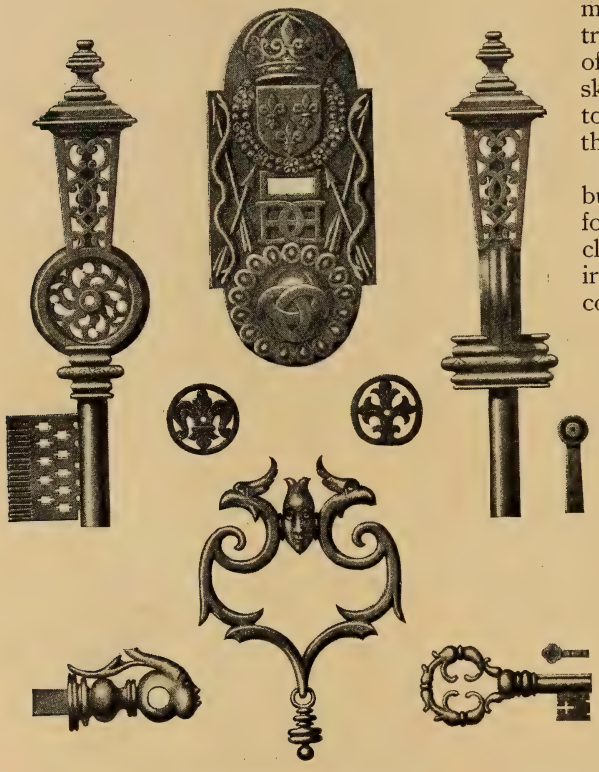


FIG. 12.—KEYS AND ESCUTCHEONS OF THE SIXTEENTH CENTURY

Cathedral, in Paris, was made in this way. The details of their ornamentation, shown in Fig. 14, should be examined carefully, as they are famous the world over.

It would be wearisome to attempt to describe in detail even a very few of the magnificent pieces of iron work, or to enter more fully into the old methods of work, but enough has been said to afford an idea of what our ancestors did with very inferior facilities at their disposal, and to show that, with all our modern machinery and improvements, there are some things that were then done as well as, or better than, they can be done now. The best work to-day is still almost entirely done by hand. The majority of workmen on such work are men who have been trained in Germany or France. At the Universal Exhibition in Paris, in 1889, in the educational department, examples of iron work, of the most elaborate character, made in the government trade schools, gave evidence of the reason for the greater skill of foreign workmen, due to the thorough instruction in their trades.

In America the fireproof building has made a demand for iron stairs, elevator enclosures, and other work in iron that has been met by a combination of wrought and cast iron, with bronze and other metals. Cast newels, stringers, fascias, with wrought iron grilles and railings, are now used, that have never before been equalled, either in design or workmanship. The designs for the castings are first modelled in wax by artists, plaster moulds and casts are obtained, and an iron pattern is made and tooled, until the character of the original is obtained. Then careful moulders, with fine sand, reproduce the pattern. The casting is cleaned and polished, and, in the best work, electroplated with some desired finish, to preserve it from rust and to please the eye. Such work calls for thorough knowledge of ornament and design, engineering ability to determine the strains and stresses, and mechanical knowledge of a high order to accomplish the results, together with large capital invested in machinery, patterns

and buildings. There is a class of work, lying between the fine work described and structural iron work and bridge building, embracing fences, railings, stairs, sheds, ornamental roofs, and other work, where ornamental effects are desired, but also where cost enters to prevent the employment of the highest class of work. Great numbers of duplicate pieces must be produced at low cost, both for material and labour. Methods of assembling the pieces must be devised that will be rigid, yet allow of rapid work. The modern manufacturer has at his disposal a host of advantages and resources unknown to his predecessors.

Primarily is to be placed the product of the rolling mill, giving the manufacturer choice of material rolled in almost any desired shape and size and of any specified quality. The invention of labour-saving machinery of all sorts has made entirely mechanical much that was formerly to be accomplished only by the skilled mechanic by hand. Thus, punching, drilling, riveting and tapping, with shearing and bending, can all be done, to a very great extent, by machine. As a result, the easiest way to get certain ornamental effects is no longer that practised by our forefathers, but follows modern lines. We often see work to-day, put together in imitation of the earlier methods, for the sake of effect. This may do for occasional pieces, but for any larger quantity of work it would be wasteful and rather ill-advised.

In addition to rolled shapes of the ordinary bar, plate or structural mill, we can now obtain certain special shapes, made exclusively for ornamental work. Mouldings, both plain and decorated, in great variety of size and contour, suited for many different kinds of work can be purchased. These are made in Germany, and the examples shown in Fig. 16 of the character of obtainable sections demonstrate that much can be learned from German workers in this field. The mere fact that there is a market in Germany for such material is itself an argument as to the character of German iron work, from an æsthetic point of view. Drop forged pickets, rosettes of all shapes, leaf forms, and various other decorative designs can be had, as also a large choice of hand-made leaf, flower and other work that could not well be machine made.

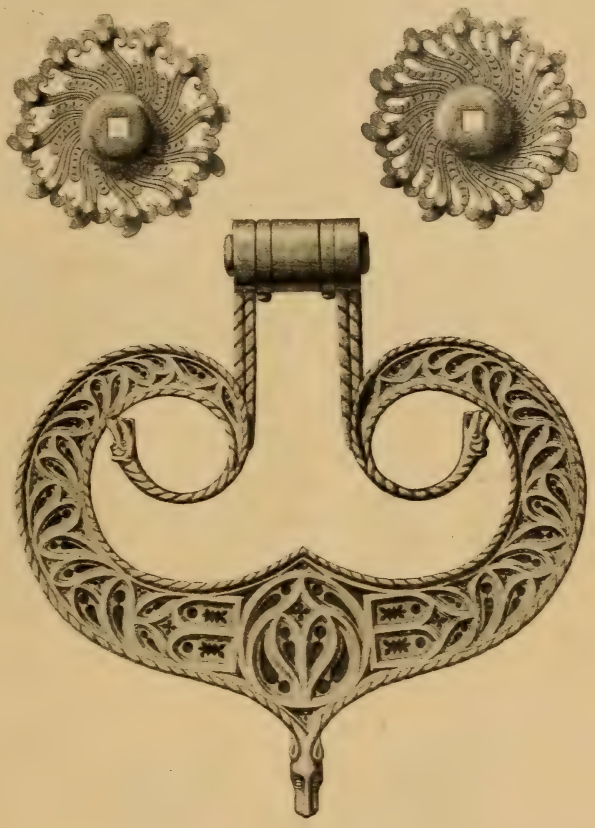


FIG. 13.—A DOOR-KNOCKER AND ROSETTES OF GOTHIC DESIGN. 1460

By the use of the ordinary and extra-ordinary kinds of material described the iron worker of to-day has only to sketch

out his idea full size, modify it a little here or there to fit the catalogue lists, order his material and work it up to produce work that in appearance, strength, and workmanship, combined with uniformity and cheapness of production, is the par of any produced by entirely hand work. But even this class of work is too costly for use where very large quantities of duplicate work are required, and hence means are used to produce ornamental effects at the very lowest possible price; in fact, at prices that vary but slightly from the present pound prices for bridge work.

As an illustration sometimes conveys information much better than whole volumes of books, a full detail of a panel for the Harlem River Speedway railing for New York City, designed by Prof. Burr, of Columbia College, is shown in Fig. 15, in which one rosette is omitted in the picture to show the construction. The top rail was oil well casing, and all

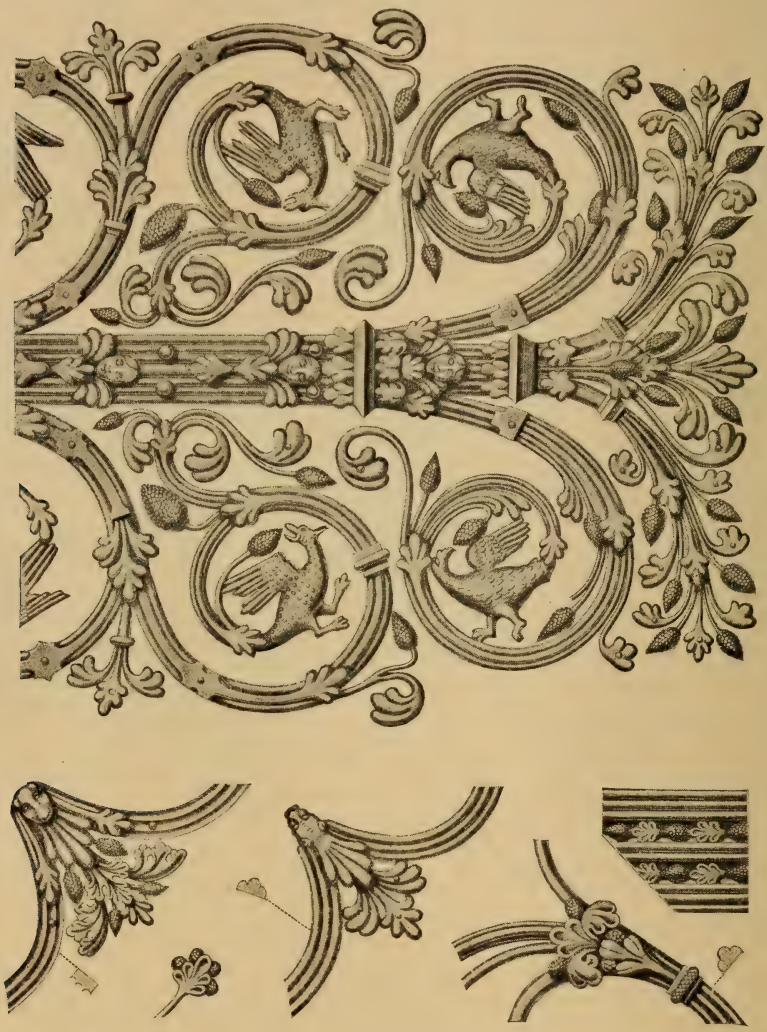


FIG. 14.—DETAILS OF NOTRE DAME CATHEDRAL HINGES. A SPECIMEN OF TWELFTH CENTURY WORK

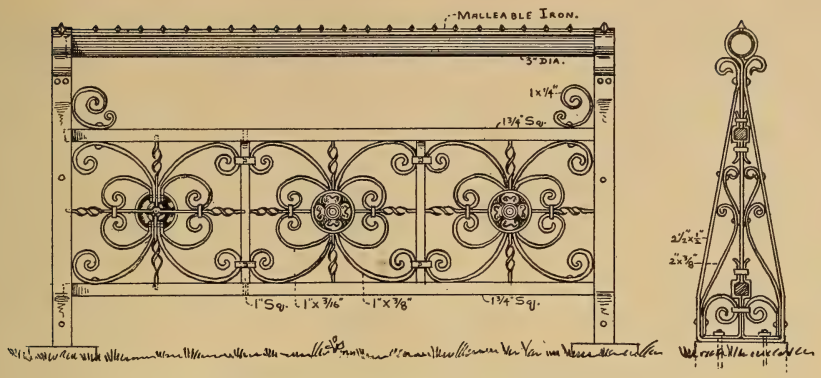


FIG. 15.—RAILING ON THE HARLEM RIVER SPEEDWAY, NEW YORK

the holes were punched by using a long bar, carrying a die in the end, inside of the tube, and a holder outside. The "teaser," or cast malleable iron pointed top piece, was all punched and sheared to gauge. The small round projections, fitting in the top pieces of the post, were to prevent the pipe from turning. The 1¾" square rails were really steel billets. The holes were at first punched, but as that swelled out the bars, they were later drilled, except the depressions holding the vertical twists in place, which were punched. The twists were machine made, cold. The nicks, or offsets, were pressed under a punching press. The scrolls were first sheared and punched, and then bent over a former to the required shape, all to gauge. The scrolls were assembled as shown, later being fitted into the special cast rosette, and finally the bands were put on and clinched with a dove-tail.

The post was more difficult. Most of the smaller pieces were first punched, then passed through a "bull-dozer" or bending machine for the preliminary bend, and then through special hand or machine formers to give the final shape. The exterior part was gauge-punched, the scrolls were beaten out and turned, and finally dropped into a form and both sides drawn around as indicated. Thus, each part was made up by the thousands, brought to the assembling spot, riveted or clamped, and passed on for painting and inspection, most of the work being paid for by the piece. As there were many grade panels, requiring special dies and forms, very close watch had to be maintained to keep the pieces separated, for the external ap-

FIG. 16.—A ROLLED IRON MOULDING

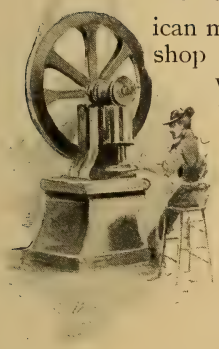
pearances were very similar. There were about 17,000 feet of this railing, weighing 60 pounds per lineal foot, or considerably over one million pounds of this comparatively light work. To lay off the vast number of duplicate pieces to be sheared and punched would be very slow and expensive work. This is avoided by means of little jigs and gauges. One method that is quite simple, for accurately spacing a lot of holes irregularly spaced along a number of bars, is to lay off the required holes, reversed, on a bar, screwed to a table, so that the bar is in line with the punch; a little dog, with a projection just fitting into the holes described, is made, having a little upwardly projecting lip. Inserting this dog into the hole furthest from the punch, the bar to be punched is shoved against the lip and hole punched in other end. The dog is moved to the next hole, the bar put again against lip, and the hole punched in the other end, of course just the required distance from the hole last punched. All that is necessary is to have the bars cut off to the right length, and no other laying out is required.

In order to execute this class of work quickly and cheaply, hand work must be largely eliminated, and ingenuity called upon to devise jigs or processes to avoid it. Architects, and, alas! bridge and structural engineers, often entirely overlook these features, and wonder why some designs of their own cost so much more than others apparently calling for much greater labour in construction. It is, of course, due to a failure to understand the construction of such work from the manufacturing standpoint, and if the designer would call in the assistance of the practical man, it would often save a great deal of needless expense, and generally result in very much improving the design of the work.

The erection of ornamental iron work requires skill and care, as in many cases lives are dependent upon the strength and rigidity of the work. In this, as in all other lines, good, honest work can be furnished only at fair prices, and attempts to lower the cost by using poor or scant materials or by inferior workmanship might, in some cases, be criminal. Engineers and architects appreciate this, and give rigid and careful specifications with their plans.

SOME REASONS FOR THE EXCELLENCE OF AMERICAN MACHINERY

By Henry B. Binsse



WITH the noteworthy extension of the market for American machinery and machine-shop products generally which has taken place within the past few years, the features which distinguish the American methods of construction and design from those of other nations have acquired a widespread commercial interest.

Generally speaking, there seems to be no very clear idea of what those characteristics are. It has been often stated that the American method is to manufacture machinery on the interchangeable plan; or that the only difference between it and the methods of other countries is in the extensive use of automatic machinery; and, again, it has been stated that Americans make better machinery because they concentrate their attention on specialties. This, however, is only half the truth. The American method, and it is a vital point in the American system, is to work between fixed, predetermined limits of inaccuracy or error. Other builders make their machine details more or less imperfect and correct the faults as well as may be in the assembling, while Americans seek to have the details right and perfect, reducing to the lowest possible the number and importance of the imperfections.

This difference in methods is not commonly grasped, and the writer, therefore, ventures upon the following explanation as likely to help to its better understanding:—Did it ever strike you while you were watching a locomotive about to leave a station with its train, how great, how immeasurable is the amount of thought and energy spent in its construction; that most of the sciences have lent their hands in its design, and nearly every class of artisan has assisted to build it; and that the form and make of even its pettiest detail have taken the deep thought of not only one man, but of a multitude?

No one who has not made it a special duty can have even a faint notion of the great difficulties met and overcome in creating that machine and bringing it up to its present perfection. Consider just one point, the assembling, the putting together of its thousand parts before it is ready to leave the shops! Perhaps over a week was employed in the final erecting. Very few can form an idea of the vast amount of thought, care and attention required, not alone to make all the parts, but so to finish them that they will fit.

To the public mind a machine is just an assemblage of shafts, wheels and details which go when power is applied to move them. Comparatively few know that if those shafts do not fit the bearings in just a certain way, and that if the axial centre lines of the shafts are not almost mathematically correct the machine will fail to work, and that the inaccuracy which, if too great, ensures the breaking down of the machine, must not exceed, in many cases, a few thousandths of an inch. Take, for example, a pulley turning on a shaft,—an elementary machine. The pulley is put in a lathe and the hole is bored for the shaft. The first difficulty is met at once,—all lathes are inaccurate; none bores a round, straight hole of like diameter through-

out. The bore of the pulley will be more or less out of round, crooked and tapering.

Of course, these errors will be very small, difficult to read, and measured by thousandths of an inch; but they are important for all their small size. A magnifying glass will show that the wearing surfaces of pulley and shaft are composed of little hills and valleys. If the pulley were to rotate on the shaft, these microscopic roughnesses would begin very soon to attack each other; presently the pulley would be fast on the shaft. By flowing a layer of oil between the pulley and shaft the wearing surfaces are kept apart and they move over this interposed smooth oil layer.

Picture to yourself these inaccuracies just mentioned as greatly magnified! Wherever the bore is out of round, tapering or crooked, at those points the surface of the shaft will squeeze out the oil and will rub against the surface of the pulley, and, if the inaccuracy be beyond certain limits, the wearing surfaces will be destroyed, as though there had been no lubricant. On the other hand, the life of the wearing surfaces will be prolonged indefinitely if the bore of the pulley and the shaft were absolutely straight, round and uniform, with smooth, highly polished surfaces, and if the shaft diameter were of exactly the size to allow the oil to flow between it and the pulley. The fitting of a machine, therefore, is of the highest importance; even a well designed machine may be wrecked by incorrect or poor fitting, and the life or wear of every machine is dependent on the workmanship shown in this matter.

In case of the pulley and the shaft the error allowable in practice is quite large. The shaft may shake in the pulley bore, the difference in the respective diameters may be one-hundredth of an inch without harm, but it is altogether another matter with other classes of machinery. In printing presses, for instance, where there is a series of successive operations, no such error can be tolerated. Here the movements are driven by gearing trains, and if the shafts shook ever so little in their bearings, the ink roller would distribute the ink unevenly, the time of the operations would become irregular and the gear teeth would break. Here, then, very close fitting is indispensable, and the error limit would be expressed in a very few thousandths of an inch.

Again, we have another condition in the marine engine. A steamer, labouring in a heavy storm, twists and bends its shape under the great ever-changing stresses. In this case and in that of the locomotive the fitting must allow for changes in alignment. In agricultural machinery it is obvious that even greater allowance must be made for the condition that the machine works over fields of grain with loose soil. Here the fitting must be very loose and shaky if the machine shall not clog.

So each class and type of machine must be fitted to meet the conditions of its use, and of them all there is none which demands greater accuracy and truth than is required in the manufacture of firearms. A good rifle should withstand almost every conceivable use and abuse without breaking down, and it should be readily repaired when out of order.

In the town of Liège, Belgium, a very important industry is the manufacture of revolvers and other small arms. The details of these are given by contract to workmen, who finish them at their homes, all the work being done by hand, practically. These details, when finished, are brought to the factory where they are assembled. The fitter, having a lot of details before him, selects a set and proceeds to make one piece match with the other. There is nothing standard about these details, and each revolver or gun made under this system is unlike the other. The grade of the work and fitting depends entirely upon the skill and good faith of the individual workman, and when out of order, the entire piece must be returned to the factory. Obviously this would be a wretched weapon wherewith to fit out an army. In this manner all firearms were manufactured until the beginning of this century.

Mr. W. F. Durfee has shown in his

papers on interchangeable construction, printed in this magazine in October, 1893, and April, 1894, that in France an effort had been made to manufacture gun locks on the interchangeable plan by special tools. If it be true that this attempt was successful and that it merits the importance which Mr. Durfee believes it does, then it needs to be explained how a nation, not usually considered dull, could have neglected the art and allowed it to perish.

For thirty years after 1785, when Thomas Jefferson was shown her gun locks, France was plunged in wars with all Europe. Is it supposable that an industry of so great, even vital, importance would fail to get attention in times like those? It is much more likely that the bright workman who conceived the idea and attempted to carry it out failed after obtaining only a partial success.

When Eli Whitney, the inventor of the cotton-gin, was unable to secure his rights for that invention and found himself loaded down with debts, incurred in the attempt, he could never have suspected that it was to be a blessing in disguise to his country and even to him. Seeing no prospect of obtaining justice, he turned his ingenious mind into another path and in 1798 he took a contract to furnish 10,000 stands of arms to the United States Government. The time for fulfilling the contract was two years.

To appreciate the difficulties of his undertaking we should bear in mind that there were few workmen and but little knowledge of the art of gun-making in the United States, and there were no machine tools. The milling machine had been described in France in some publications, but not one was in use in America. It was probably in the end an advantage to Whitney that he was forced to think out an entirely novel way to manufacture his guns. He was not only an inventor, but also a remarkable workman, having been accustomed, from his earliest boyhood, to exercise all the trades, in addition to being a hard student and a close observer. He was driven by the force of circumstances to base his plan of manufacture upon making the parts of his guns alike and of uniform excellence by special tools. His contract took eight years in place of two, but it was completed to the perfect satisfaction of the government. He continued to take similar contracts until his death, in 1825.

His factory was near New Haven, Conn., at the present village of Whitneyville; and out of this place came the Yankee tool-maker, another schoolmaster, who was destined to educate the world in the art of ironmaking. To explain Whitney's method, let us consider again the pulley and shaft. We have seen that it is very difficult and time-killing to bore out the pulley in a lathe with a turning tool. A dozen pulleys bored out in this way would all have different diameters. They may be likened to the details made by the Liège gunsmiths. Each shaft would have to be turned by itself to fit a particular pulley; each would fit only one pulley. If we rough out the pulley to nearly the desired diameter and then remove the rest of the metal by a special tool, (a reamer,) we shall get all twelve pulleys nearly alike, with holes straight and round. If, now, we make plugs, one to fit the largest and one to fit the smallest hole and turn the shafts to sizes between the plug diameters, the shafts and pulleys will fit interchangeably. Here we have the elements of Whitney's inventions,—special tools to produce extreme accuracy and perfection of workmanship, and gauges to measure and limit the amount of error or departure from the exact size desired.

In gun-making, a model is made which is taken as perfect. Two sets of gauges are made; one set is kept for reference only, and the other is sent to the shop. Every piece coming from the shop is carefully measured and tested by inspectors,—skilled workmen who do nothing else,—and every piece which fails to measure between the desired limits is condemned. In fact, the limits for many details are almost too small to be considered, being less than one-thousandth of an inch; for other details the limits are wider.

The pieces which pass inspection are

absolutely interchangeable, and a revolver or gun made by this method can reach perfection in fitting. Of course, any breakage of these arms in the field can be replaced at once from a store of duplicate parts. To obtain the desired perfection and accuracy, each operation is subjected to careful examination, study and analysis, and special tools and devices are gotten up for every operation. The workmen who do this are called tool-makers.

Comparing the two methods, we find that the Liège workman is bound down to a life of irksome toil, deadening to mind and body. Each day brings a repetition of the same work, with nothing to lighten it, nothing to render it bright or interesting. His dull task is to supply a quota of objects, chipped and filed near enough to the model to pass inspection.

As a man's faculties and energies vary from day to day, so also the quality of his work must fluctuate. The American plan is to turn the drudgery over to a machine. The tool-maker sets the machine, the special fixture or device, and when it has been started, performing the work to his satisfaction, he leaves it to be attended to by unskilled labour, while he takes up something else. Every day new problems come to stimulate his powers of mind and hand; his interest never flags, for the responsibility for imperfect work is put at once upon him. In this way he feels that he is an important part of the whole. The manufacture of machinery by this method places it on a higher plane. It requires great refinements in measurements, close observation, and careful study. It is, in fact, a training school for thinking and skillful mechanics, and it is, undoubtedly, a chief cause of the marked fertility in American inventions. The very close union which it has brought about between the designer and the workman has proved of the greatest benefit to both.

To the writer, the most striking feature in many of the European machinery exhibits at the World's Fair at Chicago in 1893 was their academic design. Evidently they had been made with but a superficial knowledge of shop practice and of what is needed for a machine to stand up to its work all the year round. With Americans it is no uncommon usage to invite criticism of the design and suggestions for improvements from the men. Written forms are furnished for these, which are gone over with great care by the management. Some works go so far as to offer prizes and rewards for valuable hints and ideas from the workmen.

From Whitney's factory his methods spread with great rapidity over all New England, and were applied to the manufacture of countless articles in metal. The art was quickly developed by a multitude of bright workers, and it was applied to heavier machines, in time, so that, at present, it is the system of all the best American workshops. Of course, it is not to be inferred that heavy machinery is built in the United States with an outlay for special tools equal to that usual for gun-making. The extent to which special fixtures are practicable depends upon the quantity of the product which may be sold.

Guns, sewing-machines, type-writers and the like will pay for a large investment in special tools. In fact, they cannot to-day be made in any other manner. The system is highly developed also in the manufacture of locomotives, pumps and other heavy machines of which the output is large. Where it cannot be applied profitably to heavy pieces, it is used in the manufacture, in quantity, of the small details. Lathe builders, for example, made the details in large lots by special tools and fixtures, keeping them in stock until needed for their orders.

In many instances it does not pay to work the large details between limits so narrow that they are fully interchangeable. In these cases, a certain amount of hand fitting is necessary, although the amount of this is less than it would have been had the work been done without any fixed limits. Therefore, work done between limits is not interchangeable of necessity. Moreover, it is not usually understood that interchangeability does not in every case imply very

close work, because the limits between which work becomes interchangeable vary greatly according to the class and kind of machine.

This method of working has given Americans a prominent place in the invention and use of automatic machines. From the use of fixtures and special tools to the fully developed automatic machine for reaching the same end it is simply a matter of a few steps; one leads up directly to the other. Hence, the infinite number of ingenious automatic machines for every purpose. Naturally, also, the system has led Americans to concentrate their energies upon special types of individual machines. The large first cost of fixtures and special tools prohibits any one from covering too wide a field, and American shops have, therefore, found it more profitable to turn out a large product of a highly perfected specialty.

A notable effect of the method is the successful standardising of details which enter into all structures of mechanical engineering. These standards have become so common that they are accepted as matters of course. Systematic mechanical training has led Americans to appreciate the value and importance of reducing all details in general use to standards, and this has progressed so far that to-day the manufacturer of machinery can buy all these things at less cost than he could make them, with any desired amount of accuracy and finish.

American methods of accurate measurement have greatly advanced the manufacture of small tools,—squares accurate within a fraction of a thousandth of an inch, micrometers in many forms which are so generally used by American workmen, scales in great variety and of extreme perfection, all at prices which put them within the reach of any one.

Thus we see that progress in mechanical engineering in the United States is not simply a happy accident, but a logical result and growth which began nearly a century ago by placing the study and manufacture of machinery on a higher plane than it had ever previously occupied. The system then commenced has produced generations of skillful mechanics of high intelligence and exceptional skill, and has developed as never before their powers of observation and invention. It has brought about a happy union between workman and designer, each respecting the other. The merit and excellence of the American machine is due to highly specialised tools and fixtures which have cost not only a great deal of money, but, what is more important, the exercise of great skill and inventive ability, and the good features of the American product cannot be copied otherwise than by like methods.

FOUNDATIONS FOR HEAVY BUILDINGS

By Professor William H. Burr

IT is probably not far wrong to state broadly that the foundations of heavy buildings may be divided into three classes:—

(1) Those which rest directly upon the earth or sand at the bottom of the excavation.

(2) Those which rest upon piles driven in groups under suitable portions of the structure.

(3) Those which are typified by the pneumatic caisson,—that is, those in which the foundation structure is carried down to bed rock or its equivalent.

In a lecture by the author, recently delivered before the Franklin Institute, and devoted to some of the features of the structural design of buildings, it was stated that the above-mentioned first class of foundations would appear to be

the simplest; yet many complicated questions may easily arise in connection with it. These earth foundations, as they may be called since the foundation bed is either earth or sand, must be so designed that the concentrated loads representing the supporting forces of the superstructure may be distributed from the points of concentration over such an area that the greatest allowed pressure per square foot on the earth shall not exceed a value which experience has shown to be safe either in respect to settlement or movement of the supporting material. Approximately speaking, it may be stated that the maximum working pressures allowable range from 4000 to 8000 pounds per square foot.

The means used for the distribution of these concentrated loads about the points of support are of considerable variety, but two methods have been largely employed, one, the older, being the inverted arch, and the other involving the use of courses of steel I-beams. The inverted arch was used for distributing the foundation pressures of the World building in New York City. This building is a very high and heavy one, and its weight is carried on wrought iron columns down to masonry pedestals which form the abutments of inverted arches of concrete. These inverted concrete arches are loaded in an upward direction by the pressure of the sand foundation bed. These arches obviously will be groined in regular or irregular series according to the location of the columns. It is a very satisfactory method of construction when the supporting earth or sand is in a suitably firm condition, and it affords an effective method of distributing the concentrated building loads. Obviously, however, it is not adapted to the softer materials which may flow under pressures no higher than those ordinarily permitted on firm earth or sand, and, furthermore, it will not usually prove to be an economical system in cost.

Another excellent method of distributing concentrated foundation loads over a bed of sand or other firm material is instanced by the foundation of the St. Paul building, in New York City, one of the more recent high buildings. In this case the bottom of the excavation is covered by a thick plate of concrete. In this plate of concrete are embedded groups of steel beams so arranged as properly to meet the imposed loads of the superstructure. These steel beams may at many points be continuous under two or more column loads, and there may be one or two or more layers of beams arranged at right angles to each other in order to distribute the imposed loads with desired uniformity. It is only necessary so to arrange the distributing beams or girders as to make it reasonably clear by calculation that the imposed loads do not exceed safe limits, as prescribed either by building ordinances or by the specifications which govern the work, such maximum limit being, perhaps, 8000 pounds per square foot. Other methods of distribution over an earth or sand foundation bed have been used, but the two described are certainly as good as any and typify excellently this class of foundation work.

The second class of foundation supports, consisting of piles driven in the bottom of the excavation to a more or less solid stratum, has been widely employed, and has given very satisfactory results under reasonably good design and execution. Groups of piles 2½ to 3 feet apart centres, are driven under points of column loading in such number that the load on no pile will carry more than the prescribed limit, which is 20 tons in New York City, and as much as 25 tons in some places, the assumption being made that the piles carry the entire load. It is then customary to excavate around the heads of the piles to a depth of 1 to 2 feet and fill concrete into and above the excavation to a depth of at least 1 foot over the tops of the piles. On the concrete footing thus formed courses of steel rolled beams are placed at right angles to each other if more than one course is used.

These rolled beams support the pedestal of the column above them, and they should be carefully protected, by water-proof courses, from any water that may find its way around the foundation.

The spaces between the rolled beams and around their ends are carefully filled with hydraulic cement mortar or concrete, the beams themselves first being thoroughly painted. The groups of piles and the courses of steel beams with the concrete footing may be continuous under two or more columns. The design of these distributing beams, so as to carry their loads without subjecting them to higher fibre stresses than are prescribed, is now well known and thoroughly understood. The upward pressure on the bottom surface of each course of beams should be taken as uniformly distributed and not concentrated along opposite edges as has sometimes been done. This system of foundations, therefore, is capable of being designed with the same degree of definiteness that is required to satisfy any advanced engineering work at the present time.

As a matter of fact, after the foundation is completed, the total loads are undoubtedly divided to some extent, at least, between the supporting piles and the earth or sand surrounding them and underneath the concrete. It is for this reason that comparatively high loads may safely be placed on the piles, and, furthermore, it may be stated that it is the chief reason why setttlement does not take place with the miserably small piles frequently used in the foundations of buildings. These piles are often not more than 8 or 10 inches in diameter at the butt and 5 inches at the tip, with a length of anywhere from 18 to 25 or 30 feet. Twenty tons upon such a pile would make an excessive load if the pile should really carry it. The practice of using these so called "toothpick" piles for heavy building construction is in the highest degree reprehensible and should not be permitted. The system, as a system, is an excellent one, but it is like any other system, in that it must not be abused if its results are to be satisfactory, and one of the most frequent and grossly inexcusable abuses is that resulting from using small sticks as piles which are absurdly inadequate to carry their nominal loads.

The third class of foundations cover those constructions which reach down from the pedestal of the column supporting the building to bed rock, or its equivalent. The pneumatic caisson has been more frequently used for this purpose than any other type of construction, although so-called hydraulic caissons or cylinders have been used in several instances.

The pneumatic caisson consists of a box or cylinder, closed on all sides but one, the open side forming the bottom as it is used in sinking. Above this caisson are extended the vertical sides of the box or cylinder, and in the interior of this box or cylinder is carried a shaft fitted with suitable valves and other details, so as to form a closed portion called the air lock. The caisson has a roof, 7 to 8 feet above its lowest or cutting edge, forming a chamber in which men may work. The shaft just mentioned leads into this working chamber, and the air lock is placed at some point above the chamber. Compressed air from air compressors continually running is forced into the working chamber and into the air lock at a pressure determined by the depth of excavation. This air pressure expels all water from the working chamber when the cutting edge is below water level, and enables the men to perform the operations required in sinking the caisson to any desired depth.

The excavated material from the working chamber is sometimes forced out by the air pressure through small pipes, or is loaded into buckets and hoisted through the lock and shaft by the manipulations of appliances which prevent the escape of any sensible amount of compressed air. The caisson is sunk in the manner described until its lower edges reach bed rock or other hard material, the cylinder in the meantime having been loaded with pig iron or other heavy weights, which force it down against the upward pressure of the air and the friction of the material on its sides as the excavation is made in the working chamber. After the desired depth is reached, the rock is carefully cleared or cleaned of all soft material, and the working chamber is filled with concrete by the men as they

finally withdraw from it. The air lock is then removed and sometimes a portion of the shaft. The remaining portion of the shaft and the volume of the cylinder outside of it are then filled with hydraulic cement concrete to its top. If desired, a stone capping may be placed upon the cylinder to receive the pedestal under the column above it. By this means the support of the building is carried directly to bed rock or its equivalent. These caissons, either rectangular, circular or oblong in horizontal section, may be of any size, from a diameter just large enough to allow one man to work, up to dimensions large enough to receive two or more columns.

Circular cylinders have also been sunk by fitting jets or nozzles to their lower edges and forcing water through them under a comparatively high pressure. The escaping water washes away the sand and other material and allows the cylinder to sink into the annular space thus made free of sand or earth. After the cylinder has been sunk to the required depth the water is kept pumped out from its interior and the sand or earth is thus excavated in the dry. As the excavation proceeds the cylinder is braced internally, so as to prevent collapse until the bottom is reached. The bottom is then properly prepared to receive concrete, with which the interior of the cylinder is filled, the braces being removed as the concrete filling is completed.

Much has been said and written about the superiority of carrying foundation supports to bed rock. It is undoubtedly satisfactory to have foundation supports carried down to rock, but it is difficult to see wherein the pile foundation fails to answer an equally satisfactory purpose when properly designed and executed. The metallic portions of pneumatic caissons and hydraulic cylinders will, within a period not by any means indefinitely long, corrode and disappear. Under proper design this is not a serious feature of the matter, but it is a feature which demands that the concrete mass shall be made as nearly monolithic as possible without unnecessary divisions by metallic plates. On the other hand, if piles are used below the water level, as they should be, they are indestructible, and will, so far as we know, remain in place for all time. On the whole, it would appear, both from rational considerations and irom engineering experience to the present time, that the question of selection of either system of foundation may be based upon economical considetations only, the design and execution being assumed to be excellent in either case.

THE AUTOMOBILE SITUATION

By Hiram Percy Maxim

A TRIAL SPIN WITH LADIES IN CHARGE

IN New York City to-day there are about a hundred motor hansom and coupé cabs in public service; about twenty motor waggons are engaged in the delivery of light merchandise; and there are between thirty and fifty private motor carriages, usually carrying two passengers. In London there are to-day about forty motor coupé cabs in public service, and fully three times as many private motor carriages as in New York, and about as many motor delivery waggons. In Paris there are twelve public motor coupé cabs in regular service, a large number of motor delivery waggons and three or four thousands of all types of private motor vehicles. Other cities also have motor vehicles in use within their areas, but the three cities mentioned are all that it is necessary to study to indicate the present condition of affairs. In London, Paris and New York every one of the public motor hansom or motor coupé cabs is propelled by the electric system, using electric storage batteries. In New York about 95 per cent. of the private motor carriages are similarly propelled, and every one of the delivery waggons as well. The remaining 5 per cent. of practical private motor vehicles which are seen upon the streets and in regular use are propelled by gasoline engines. In Boston, where local causes have affected development, steam takes about an even place with gasoline. In London not more than 20 per cent. of the private motor vehicles used regularly are propelled by storage batteries. The remaining ones use gasoline engines, or "petrol motors," as they have been called. The motor delivery service, both heavy and light, is almost entirely accomplished by steam. In Paris about 95 per cent. of the private motor vehicles are propelled by gasoline engines or "moteurs á pétrole." The same is probably the case with the motor light delivery waggons. The other 5

A MAIL COACH. BUILT BY MM. PERIN, PANHARD & CO., PARIS

A GASOLINE ENGINE PARCELS VAN. BUILT BY THE DAIMLER MOTOR COMPANY, LTD., COVENTRY, ENGLAND

per cent. of all vehicles in use may be safely said to be equally divided between electricity and steam, the latter being almost exclusively used for heavy traction. These facts, then, illustrate the situation to-day, and an examination of them, together with a knowledge of detailed technical and other conditions, indicates accurately what is happening at the present time in the motor vehicle world. There is every reason for us to recognise that for short distances, for relatively light loads and courses within a limited area, the electric system has succeeded in forcing out all other systems; for heavy weights and long distances steam has succeeded in displacing all competitors; while for high speeds, for indefinite distances and light weights, the gasoline engine has proven best suited. This classification we are compelled to accept as a resultof the survival of the fittest after a protracted struggle.

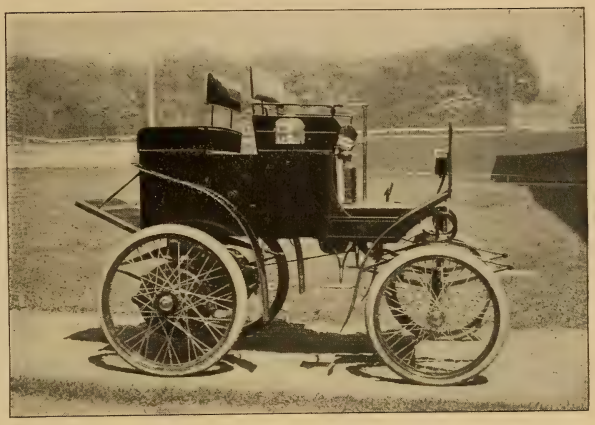
Electrical engineers have bent their energies to improving the electric stor-

AN ELECTRICALLY DRIVEN VICTORIA. BUILT BY THE FISCHER EQUIPMENT COMPANY, CHICAGO

age battery and to force the electrical vehicle into all fields; mechanical and gas engineers similarly have struggled to make the gas engine best for all services, and steam engineers have tried hard to make steam fill every want. The competition, in fact, has been satisfactorily severe, and the situation to-day may safely be taken as a healthy one, and, as has been stated, representing a survival of those best adapted for the different services.

Now for the actual defining of the limitations of these different systems and an endeavour to correct some of the misapprehensions publicly held, let us examine first the electrical system!

In public city service, it is obviously necessary that a cab, in order to be successful, must be absolutely controllable in heavy traffic even in comparatively unskilled hands, free from unpleasant odours and the general mechanical disadvantages usually inseparable from an engine, and this, added to the limited requirements of cab service as to mileage, makes it easy to understand why the electrical system has been the most successful. How long this state of affairs will exist depends entirely upon what is accomplished with the other systems. As improvement in the capacity per pound of storage battery is, to all appearances, advancing more rapidly than improvement in gasoline, steam, or other systems, it does not seem likely that electricity for cab service will very soon be supplanted. In the case of the private



A "DOS-À-DOS," DRIVEN ELECTRICALLY. BUILT BY THE COLUMBIA ELECTRIC AND VEHICLE COMPANY, HARTFORD, CONN., U. S. A.

A TYPICAL AMERICAN ELECTRIC SURREY. BUILT ALSO BY THE ABOVE COMPANY

A DAIMLER GASOLINE ENGINE OMNIBUS

A REPRESENTATIVE AMERICAN GASOLINE AUTOMOBILE FOR LIGHT SERVICE.

AN ELECTRIC DELIVERY TRICYCLE. BUILT BY THE COLUMBIA ELECTRIC AND VEHICLE COMPANY

motor vehicle, the requirements are not as uniform as with the public cab, but nevertheless there has been enough experience to permit classification of the different requirements and to understand their limits. It does not seem to be generally understood that the intentions of the owner regarding his motor carriage invariably determine the best system for his purpose. Other things being equal, the electric carriage is generally preferred on account of its extreme simplicity of operation, its ability to meet almost ideal æsthetic demands, and its instantaneous availability. The limitations of the best electrical carriage on the market to-day are, therefore, an index of the status of the electric carriage.

A TYPICAL NEW YORK ELECTRIC CAB

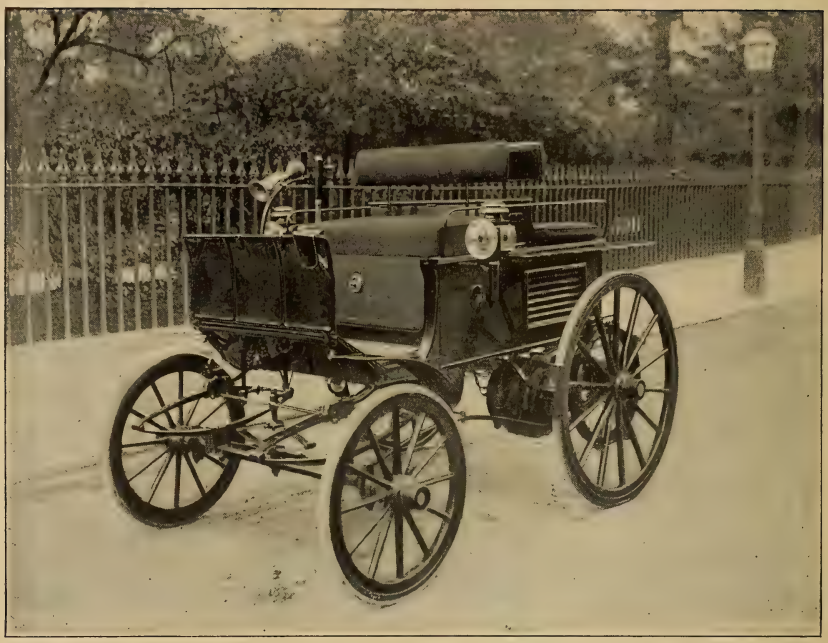
A FRENCH GASOLINE TRICYCLE

A HEAVY FRENCH GASOLINE CARRIAGE BUILT BY MM. PERIN, PAINHARD & CO.

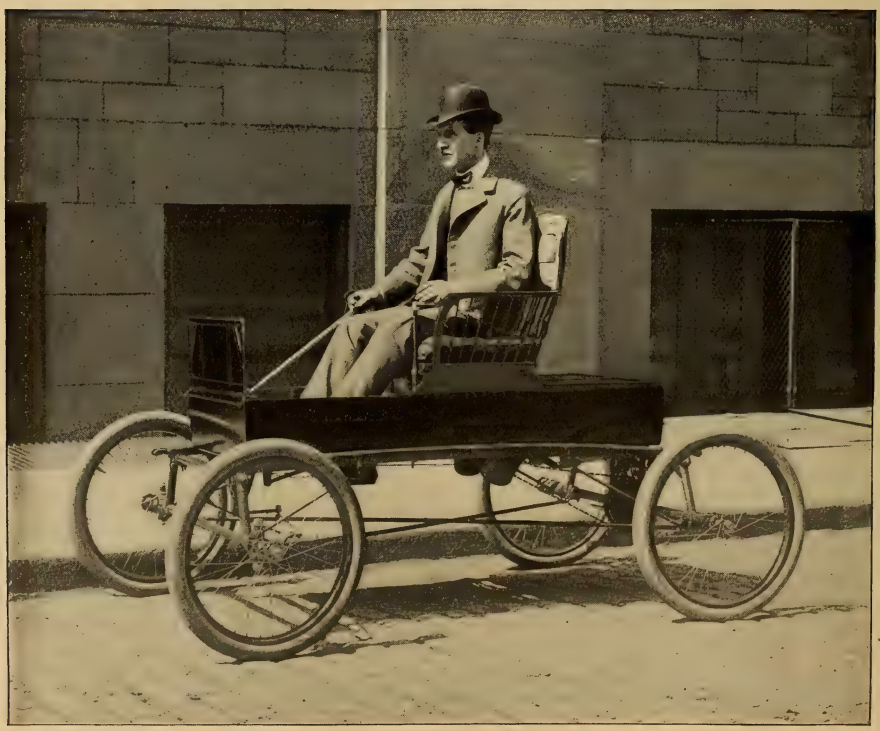
It is possible to buy to-day in America an electric carriage which will carry either two or four passengers a distance of 30 miles over ordinary grades at an average speed of 11 miles an hour on one charge of its storage battery.

The operation of the carriage is the simplest of all. The maintenance consists in keeping the motor commutator and brushes clean, bearings oiled, nuts tight, charging batteries, and, from time to time, adding to the electrolyte in the batteries enough water to make up for evaporation and decomposition losses. In practice it is found that this is all that is really required, and that but little difficulty is experienced if the carriage is turned over to an ordinary stable man after taking a little pains in his instruction.

These, then, are the limits of the electrical private carriage, and we may take the limits of the electrical delivery waggon from them, as the only difference between the two is in the style of the body and the strength of the parts. If the requirements are such that all runs will be limited to 30 miles in length and the load to be carried will be under 1000 pounds, the electrical system is the best



A FOUR-WHEELED DOG-CART. BUILT BY ELECTRICAL UNDERTAKINGS, LTD., LONDON

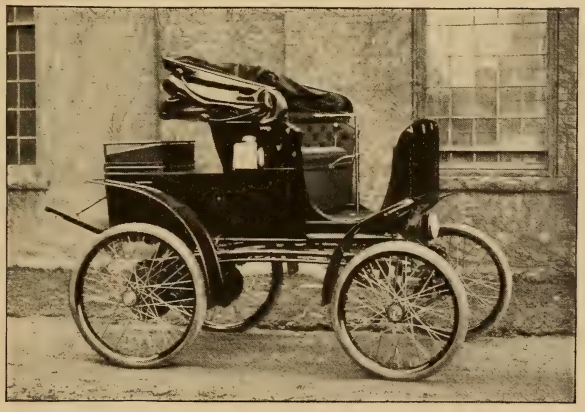


A GASOLINE RUNABOUT. BUILT BY THE PITTSBURGH MOTOR VEHICLE COMPANY, PITTSBURGH

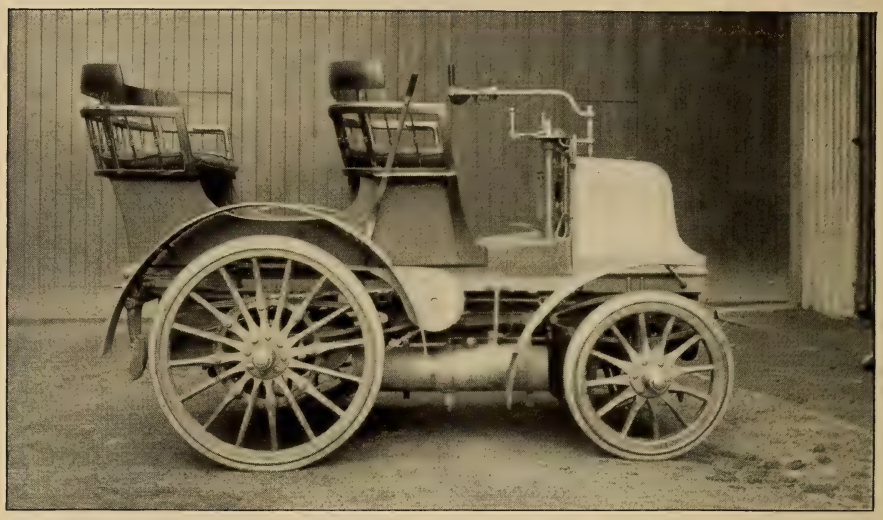
A TYPICAL FRENCH STEAM OMNIBUS

for carriage or delivery waggon. In practice, these limits are found to include almost all city physicians' service, city pleasure driving, general running about, and city delivery service. As an example of taking a carriage out of its field, the writer might refer to an attempt at touring in an electric carriage which he made at one time. He succeeded in covering a distance of something over a hundred miles through country districts, but at the expense of all sorts of inconveniences and delays, which completely removed all pleasure from the trip. Now let us examine the status of the best vehicles of other systems as they exist to-day! If one wishes to make runs exceeding 30 miles in length, to carry less than 1000 pounds, and to avoid the necessity of having any definite base of supply, either the gasoline carriage will be chosen, thus following the example of 75 per cent. of those who use long-distance carriages in the United States, or the steam carriage, which represents the remaining 25 per cent. If he follows the practice in Great Britain, the user will buy a gasoline carriage, and the same is the case in France. Of the gasoline engines used on both sides of the Atlantic in regular vehicle service and in the hands of private owners not interested in their manufacture, fully 99 per cent. work on the Otto cycle, with one working impulse for every second revolution per cylinder. Last year the best gasoline equipments were made in Europe.

To-day it is more than probable that the best gasoline equipments can be obtained in America, although it must be



A TYPICAL AMERICAN ELECTRIC PHAETON



ANOTHER FORM OF GASOLINE ENGINE CARRIAGE. BUILT BY THE DAIMLER MOTOR COMPANY, LTD.

understood that there are also inferior ones offered for sale there. The best American gasoline carriage is to-day an entirely practical and serviceable vehicle. It can be depended upon every day in the year if it be given reasonable opportunities. It requires more skill to operate than is necessary with an electric carriage, and considerably more skill to maintain it.

In practice, successful operation is found to require, first, a general understanding of the scheme of the machine. The detailed procedure of running commences with the starting of the engine, which is usually accomplished by a hand crank,—a simple and convenient operation,—the setting of the gear lever in the notch which is desired and the closing of a friction clutch. In the systems most in use the operation, after the engine has been started, is as follows:—There are two pedals in the floor of the carriage. One operates a friction clutch which connects the engine to the driving axle; the other controls the brake, and, at the same time, disconnects the friction clutch. At the side of the seat there is a lever and notches in which to place it. To start the vehicle, the clutch or left pedal is pressed down by the left foot, the lever beside the seat is placed in the first notch or "hill-climbing gear," and the foot is slowly lifted and the pedal allowed to gradually rise. When this pedal has risen as far as it will go, the vehicle is in gear and running at the speed of the hill-climbing gear.

If the grade or road is such as to permit of putting in a higher gear to get a higher speed, the left pedal is pressed down again, the lever beside the seat is placed in the next notch ahead, and the pedal is again slowly allowed to rise, as before. Sometimes there are three notches; in racing carriages there are four. To stop the vehicle, the right pedal only has to be pressed. This disconnects the friction clutch, and, at the same time, applies the brake. To leave the vehicle, the lever beside the seat is placed in the "stop" or "off" notch, when the pedals can assume any position they see fit. In addition to this there is usually a handle by means of which the engine governor can be thrown out of gear, so as to give the maximum speed at which the engine will run. A handle is also provided by which the mixing of gas and air can be altered and adjusted.

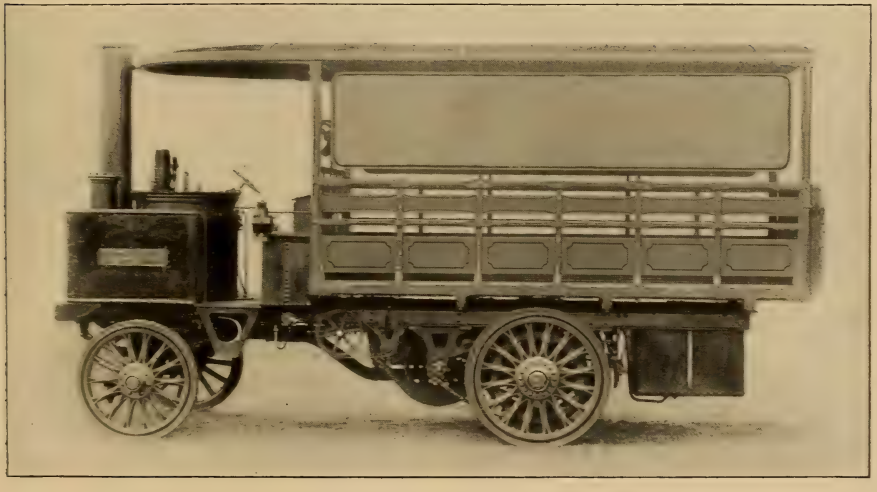
The gasoline used in the best machines is what is generally known in the trade as 72 degree. Any gasoline or naphtha is suitable, although that be-

tween 68 and 74 degrees gives the best results. This can be purchased throughout the United States at a price which averages fifteen cents per gallon. In the best gasoline carriages in which two passengers are carried and which, without passengers, weigh about 700 pounds, the consumption of gasoline is, on ordinary country roads, about 0.06 gallon per mile. The cost can, therefore, be readily calculated.

The ignition in the best machines is accomplished by a magneto-generator which is entirely automatic. Lubricating oil is used at about the rate of a pint for every 50 or 100 miles, depending upon the quality and the conditions. This oil usually costs forty cents a gallon.

A TYPICAL FRENCH ELECTRIC CAB. THE BATTERIES ARE CARRIED IN THE BOX BELOW THE CAR BODY

The maintenance of the vehicle consists in keeping the engine mechanism in order. The skill necessary to maintain it is precisely the same as that necessary to maintain any hard-working gas engine. A machine would be practically useless in the hands of any one not having mechanical inclinations, whether he be the owner or the stable man. General instructions to stable men have not been successful. On the continent, the owner of one of these vehicles, if it is a carriage, invariably has a man who has spent usually two weeks at the manufacturer's establishment, where he becomes familiar with the construction of the machine. In



A STEAM WAGGON. BUILT BY THE STEAM CARRIAGE AND WAGGON COMPANY, LTD., CHISWICK, ENGLAND

the case of purchasers of gasoline tricycles, such as the well-known De Dion, which is used very generally on the European continent, and where the owner has no mechanical inclinations, the outfit is usually cared for by one of the many companies who make a specialty of looking out for these machines. They are kept in order at a fixed rate per month, though repairs of any magnitude are charged for extra. This feature of maintenance in the gasoline carriage has, in the United States, confined the use of the vehicles principally to owners who take some interest in mechanical devices, and who derive more or less pleasure from keeping the little mechanisms in working order. Practice seems to indicate that it is a question of personal interest in the machine, rather than engineering ability.

M. Serpollet

A FRENCH STEAM AUTOMOBILE ON THE SERPOLLET SYSTEM

THE STANLEY STEAM AUTOMOBILE. BUILT BY THE MOBILE COMPANY OF AMERICA, NEW YORK

The type of gasoline carriage which in America is most popular is the lightest possible machine that will carry two people seated abreast. The vehicle is sometimes provided with a weather protecting top, but frequently without anything of this nature. It is used for city running about, and, in the pleasant seasons, for long-distance touring. In Great Britain and on the Continent the most popular type of vehicle of this class is one carrying four passengers and weighing about 2500 pounds. These are used for long-distance touring, and, when fitted with quadruple engines, are used for the very high-speed racing indulged in there. The other form of machine extremely popular is the De Dion tricycle, practically the smallest and lightest machine that will carry one passenger, seated upon a bicycle saddle. These machines are capable of fairly high speed, weigh about 175 pounds, and are capable of running independent of any fixed base of supplies.

No generally successful results are being obtained with the gasoline engine where the load to be carried exceeds 1500 pounds. Isolated cases have been recorded, but there is not a great number of machines in every-day service. As for steam car-

ANOTHER FORM OF STEAM WAGGON. BUILT BY THE STEAM CARRIAGE AND WAGGON COMPANY, LTD.

riages, these have been produced especially in the vicinity of Boston, in the United States, and, in a few instances, apparently perform the regular service in which light gasoline vehicles elsewhere excel. They are operated by a small steam boiler placed under the seat, and a very small high speed steam engine, geared to the driving axle. The weights are very much less than in the case of the gasoline carriage, sometimes as much as 50 per cent., and the speeds are very high. The operation, of course, becomes one of managing the throttle and the cut-off links of the engine, and the water level in the boiler. The fire is made to automatically take care of itself in the best vehicles. A cloud of visible steam at the exhaust is difficult to avoid, and there is always a slight roar from the fire which is usually one of gasoline, burning in a large Bunsen burner. The maintenance of the vehicle may be compared directly with the maintenance of the gasoline vehicle. There is an engine and a steam boiler, and the usual mechanical appliances connected with such devices.

The steam carriage is able to fill the unlimited distance requirements as well as the gasoline vehicle. Its peculiarities, however, are decidedly different, and there are very few successful light steam vehicles in daily use, as compared with the number of successful gasoline vehicles in daily service. For weights exceeding 1500 pounds and distances exceeding even ten miles, however, steam has proven more successful than anything else. In Great Britain there are several vehicles in regular use for carrying heavy loads of general merchandise. In France the same condition of affairs exists in the transportation of large numbers of passengers and heavy merchandise. From a knowledge, however, of experiments that are being made on both sides of the Atlantic, it seems very probable that, at least for the transportation of heavy loads of passengers over fairly long distances, other systems will be developed in the

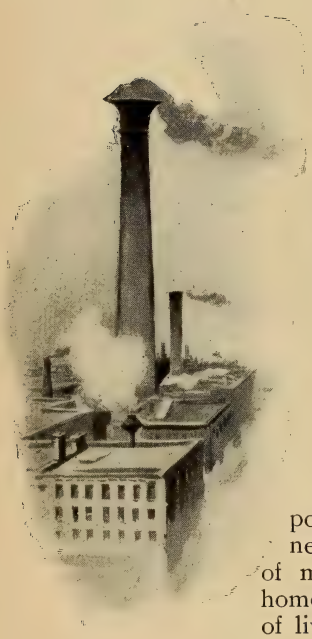
A REPRESENTATIVE FRENCH LONG DISTANCE GASOLINE RACING AUTOMOBILE. BUILT BY MM. PERIN, PANHARD & CO.

near future which will seriously compete with steam. As this is all a question of the future, and there is little likelihood of something immediate being regularly installed, it is without the scope of this article.

The motor vehicle situation, then, as we have to face it to-day, offers three different practicable systems for the propulsion of road vehicles. All three are eminently successful and satisfactory in their field, but none of them completely fills all fields. Instead of the broad statements which we see continually that this or that system is the best for all services, we find that it depends entirely upon the requirements and limitations of the particular case in question.

THE UTILISATION OF WASTE

By John Birkinbine



WHAT is the waste or refuse of one industry may be, and often is, the raw material of another, but the extent to which such waste can be used is influenced by local conditions. As remarked by the author in a paper recently read before the Engineers' Club, of Philadelphia, it is comparatively easy to point out waste in nearly every process of manufacture, in our homes, and in our method of living; but to correct this is, in many instances, impracticable. We recognise how great the waste is in all departments of industries and in our households, and few realise how much is being done toward utilising this refuse material. But with all that has been accomplished, there is a wide field to be covered before we reach the Utopian condition where a useful purpose is found for all that is now waste or considered as such. The many scavengers who extract value from the proceeds of the city dump heaps in waste paper, rags, old leather, coal, bottles, or old metal, probably represent the most popular notion of the utilisation of waste products,—a utilisation more important than is ordinarily appreciated, and representing gross money value which would appear fabulous. The army engaged in this reclamation is large, and its scouts appear at every dump, upon the scenes of every fire before the embers are cooled, or assail our homes to collect whatever of apparent value may be obtainable.

The late Colonel Waring, while at the head of the New York Street Cleaning Department, asserted that in the present state of knowledge the refuse from a city of 50,000 inhabitants possesses sufficient commercial value for the municipality to derive revenue from the sale of the privilege of collecting it. The facts that old rags and paper enter into the production of other paper, that scrap-iron and other metals are transformed by the cupola or furnace into new forms, that leather-scraps are useful in chemical manufacture, apparently cover the extent of popular knowledge. An inventor of a pulverising apparatus, in inviting attention to his invention, asserted that his machines were employed to reduce old bottles and broken crockery into impalpable powder as a constituent of a well-advertised scouring soap. The city waste is of enormous

proportions, and the refuse from homes and manufactories is great. In addition to the manufactures or special industries which depend upon the waste of others for raw material, there are those which are profitable only because their waste is put to some useful purpose. In some instances the original product is now the by-product, and what was formerly refuse represents the greater proportion of value.

The possibilities of utilising waste in a single direction were suggested by a visit to a large button-works, where I was informed that ninety tons of buttons had been made in one month. It is impossible to suggest the number of buttons represented by ninety tons, or to imagine the multitude of stitches required to fasten them to clothing, or even to guess at the number of "swears" which were encouraged by the failure of individual buttons to maintain their responsibility. The material used to produce these buttons was the remnants of the sheets of tinplate from which the buttons and caps of cans for blacking and other boxes had been cut. After the button blanks had been punched from this tinplate, the small triangles of metal connected by iron threads were compressed in a form under a drop-hammer and subsequently shipped away to be made into sash-weights.

Some of the prominent utilisations of waste products which are well known to-day are in connection with the fuel supply. In the production of charcoal from wood there are large volumes of acetic vapours which, when condensed, are of considerable value. By charring the wood in ovens or retorts and conveying the vapours to condensers and stills, the products are charcoal, pyroligneous acid, tar, and uncondensable gases of considerable thermic value. These gases are used as fuel, the tar is merchantable, and from the pyroligneous acid methyl alcohol, acetic acid, and various commercial acetates are produced. The influence of locality is quite marked in this utilisation, for at some ironworks many thousand cords of wood are annually converted into charcoal, the pyroligneous acid as a by-product being made into acetates and wood-alcohol. At other works the wood is charred to secure the pyroligneous acid, the charcoal being a by-product, but most of the wood cut for charcoal is charred and no effort is made to collect the acetic vapours.

The same principle holds in regard to the manufacture of coke. As a rule, the products of distillation from the coal while being coked pass off into the air as dense smoke and are wasted, but at a number of localities the volatile matters are condensed and commercial ammoniates, tar, and gases of calorific value are utilised. It is claimed that, in addition to the commercial by-products from coking ten tons of average bituminous coal, incondensable gases, equivalent in calorific value to one ton of coal, result.

A liberal portion of the coal supply of Philadelphia to-day is made up of sizes which were considered unmerchantable, and which were consigned to the waste-heaps within a few years. Now this coal finds a ready market, and piles of refuse are being reworked to secure the smaller sizes of coal available, and in some cases the refuse from the washeries (which is mainly disintegrated shale) is utilised to fill the portions of the mines which are worked out. Coal-waste was considered of sufficient importance to have a Pennsylvania State Commission appointed to investigate it a decade ago. Special furnaces and grates to utilise this small coal are designed, and there is widespread interest in smoke abatement. The disintegration and washing of inferior coal to produce coke, the employment of the gas-producer, are incidental to the utilisation of what otherwise would be wasted.

A prominent American utilisation is the cotton-seed. Throughout the cotton belt of the United States numerous mills are operated which convert the cotton-seed, formerly left in piles to rot or to be burned when sufficiently dry, into oil and food for cattle. Cotton-seed mills are features of many Southern towns, and are sought for as industrial developers by municipal promoters. The cornstalk, whose only functions ap-

peared to be to contribute to the manure-pile or to serve as food or bedding for cattle, seems destined to find a considerable utilisation in producing cellulose. The pith of the cornstalk is treated to produce this remarkable product, the balance being transformed into compressed cattle food.

In the iron industry there are numerous applications in utilising waste or refuse, including the production of cement, mineral wool, paving blocks, or monolithic paving, from blast-furnace cinder; the remelting or converting of unmerchantable masses of metal, ladle-sculls, crop-ends, shearings, punchings, filings, etc.; the rerolling of rails; the utilisation of blast-furnace gas to heat air, produce steam, etc.; the restoring of the exterior heat of an ingot by means of a soaking pit, and the sinking of scrap in forges and furnaces; the almost universal generation of steam by waste heat, and many others.

One need not be classed as old to recall the scum which formerly covered every stream draining a gas works. The resulting tar, the ammoniacal liquor, the coke, are all now put to use, and from the former some marvelous products result. We would hardly suspect the sweetest substance known, or the nearest imitation of the flavour of the vanilla-bean to be coal-tar products, nor do the marvelous anilin colours suggest coal as their ancestor. The petroleum industry abounds in interesting surprises of products made from what was formerly waste. Many carbons used in electric engineering are formed of what was a waste product from petroleum distillation, or from gas retorts.

The various systematic methods of exploiting mines and applying timber supports to the workings permit of obtaining a larger proportion of mineral from a given area, and the application of chemistry to metallurgic processes aids in extracting from what was formerly waste rock much that is of value. The chlorination, the cyanide and other processes, recover precious metals from what, until late years, was considered unproductive rock. The condensation of fumes resulting from roasting ores, the treatment of acids or liquors which have performed their purpose in manufacturing processes, are instances of the utilisation of waste. The American mining city of Butte, Montana, is now demanding some process which will utilise the sulphurous fumes from the smelters, which make life in that city undesirable—a waste product which some day will represent great value, but to get rid of which now demands large expenditures.

Water strongly impregnated with copper is pumped from the copper mines, passed over old scrap-iron, to which it adheres, and in this way large quantities of fine copper are recovered. The blue billy, which is a by-product in the treatment of iron pyrites for the manufacture of sulphuric acid, is an important portion of the charge of many blast-furnaces, and the silicate of iron, left after abstracting copper from cupriferous pyrites, has a similar use.

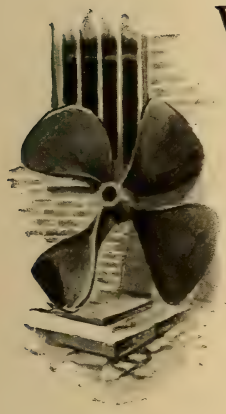
The lumber industry supplies numerous instances of refuse utilisation, and in many localities the proportion of slabs and strips fed to the furnace is much below what prevailed a few years ago. The cores cut from pump-logs are made into pillars or round posts, the slabs are cut into box-boards or lath, shingles, etc., and sawdust, compressed with a cementing medium, is also formed into imitations of carving. A number of minor woodworking industries rely upon the waste from sawmills, and in the mills the effort to reduce the loss in sawdust has developed the band saw with its narrow "kerf." At some Swedish iron and steel works sawdust and sawmill refuse are gasified, the gas, after being freed from moisture, being used as fuel.

Instances of utilisation might be multiplied, but those mentioned may suggest various other means employed in special industries to convert to a useful purpose what was refuse. The admission that in our modern steam-engine only a modicum of the calorific energy stored in the fuel is used, shows that a wide field is still before us in reducing waste. The water powers which are being utilised demonstrate how great is the power which has

been permitted to go to waste, and which in many cases may be conserved. Perhaps enough has been said to suggest how numerous are the utilisations of refuse, and how many are the opportunities for future advances. That there is a use for everything we all admit; that practical use can be made of everything will depend largely upon local conditions. But it is evident that the industry or municipality or home which is able to obtain the greatest value from what under normal conditions is wasted most nearly approaches this ideal.

THE RIGHT HONOURABLE WILLIAM J. PIRRIE, P.C., C.E.

A BIOGRAPHICAL SKETCH



WITH the launching, a few months ago, of the gigantic White Star Line steamship *Oceanic*,—the largest vessel now afloat, measuring 704 feet in length, 68 feet in breadth, and 49 feet in depth, with 28,000 tons displacement,—it is not uninteresting at this time to give a brief biographical sketch of her designer and builder, the Right Honourable William James Pirrie, of the world-renowned firm of Harland & Wolff, of Belfast.

Mr. Pirrie was born at Quebec in 1847, but on the death of his father he was brought over to the north of Ireland when only a year old, and spent his early childhood at the old family home at Conlig, County Down. He was educated at the Royal Belfast Academical Institution, where he gained great distinction in mathematics, and at the early age of fifteen he entered the establishment of Messrs. Harland & Wolff, shipbuilders and engineers, as a pupil. With that firm he has been identified ever since in successive stages of importance and influence,—as pupil, draughtsman, outside chargeman or sub-manager, assistant manager, works manager, partner, principal, and now chairman and managing director, his position to-day being one of the proudest that a man could possibly occupy, having the control of an establishment which is among the first of its kind in the world, employing about 10,000 men, with a wages bill of something like £12,000 to £14,000 weekly, turning out some of the largest and finest ships afloat and with an annual output of 84,000 tons.

It is not, however, merely Mr. Pirrie's connection with such a firm that places him amongst those of whom the public is always interested to hear; it is the fact that the firm's success is his own; it is he more than any other man that has brought the establishment to the commanding position it now occupies. The rapid development of the Queen's Island Shipbuilding and Engineering Works, Belfast, until in capacity, equipment, organisation and successful working they are excelled by none in Great Britain or elsewhere, has been the creation of his own energy, ability, industry, organising power, tact and judgment, and although he is always the first to acknowledge the effective co-operation and assistance he has received from those who have been associated with him, all who know what he has done for the great industrial establishment with which he has been connected all through his busy commercial life recognise that the arrangement and order and the efficient administration and working of the colossal concern in its present state of perfection is the outcome of his genius, his indomitable energy and perseverance and his progressive spirit,—that his is

the master mind controlling the destinies of the firm and adding to its success year by year.

Perhaps one of the secrets of Mr. Pirrie's success lies in the fact that, in the pursuit of his profession, he has traversed every ocean and made himself acquainted with the conditions of life at sea in the different quarters of the globe and also with the nature of the facilities for working steamers at all the leading ports of the world. In the United States and Canada, at the Cape, and in the Pacific he has personally inspected the various harbour works and trading facilities, and, being a very keen observer, he has acquired a knowledge of the needs and requirements of the shipping trade that probably very few men of the present day possess to an equal extent.

This knowledge he has turned to the greatest advantage in the interest of his shipping friends, a fact which, taken in conjunction with his well-known integrity, has caused them to place such confidence in him that probably (except in the case of his predecessor, Sir Edward Harland, with whom, however, it had not been extended to the same degree) his relations as a shipbuilder with the leading shipowners and shipping companies is altogether unique, and many other companies now follow the example of the White Star Line by placing orders with Messrs. Harland & Wolff on commission terms without a formal contract, the only stipulation being that the best ship shall be constructed for a given purpose as economically as may be consistent with good design and workmanship and the use of the best materials.

Perhaps the chief point of interest in Mr. Pirrie at the present time is the fact, already mentioned, that he is the designer of the White Star steamer *Oceanic*, the largest vessel afloat, and which was launched last January. Mr. Pirrie is particularly proud of this vessel, as well he might be. She will be the crack vessel of the White Star Line, whose famous ships, the *Teutonic* and *Majestic*, built at the same yard ten years ago, are even to-day favourites with a very large section of the travelling public, both in America and Great Britain, and are probably unsurpassed for their comfortable appointments and good sea-going qualities.

The *Oceanic* will be the largest vessel of the nineteenth century, and to have been the builder of such a ship is an honour that a few years ago hardly any one would have dreamt of being wrested from Brunel, the builder of the historic *Great Eastern*.

The *Oceanic*, moreover, in addition to being the largest, will undoubtedly be the finest vessel that has been thus far produced, no expense having been spared to make her so. Before the keel was laid, about £20,000 were spent in the special preparation of the slip and the construction and placing in position of a huge gantry nearly 100 feet high and over 90 feet wide to traverse the whole length of the ways with hydraulic riveters, electric drills and other tools, and heavy weights. By this means all the most important rivetting in the ship was done by hydraulic power. The *Oceanic* will have the additional advantage that she will be by far the strongest structure that has ever borne the designation of a ship.

Considerable interest was manifested in regard to the launch of the vessel owing to her great length and weight being so much in excess of any vessel hitherto built, and the successful accomplishment of this has been described as the greatest engineering feat of the century. In design and construction it is claimed that the *Oceanic* is a great advance on anything that has yet appeared, and in view of the experience Mr. Pirrie has had in the construction of the best and largest type of steamers she will probably represent the highest point of excellence in naval architecture and marine engineering that has yet been reached.

All these facts concerning the *Oceanic* will help to a fuller realisation of the important and unique position occupied by Mr. Pirrie. Many of the improvements introduced during the last twenty years in marine construction were initiated by him and were adopted by others only after he had clearly demonstrated their

value in vessels of his own design. One of his strongest points has always been the advantage of twin screws, and so little was this recognised at first that for years many of his friends and others looked upon it only as "one of Pirrie's hobbies." So rapidly have twin screws gained in favour, however, that to-day hardly any large passenger boats are built with only one screw and one set of engines.

In the matter of size of ships he has also been a pioneer, and although his example has been followed, he has made the pace so fast that his firm is still a long way ahead in the race for supremacy in this direction. One more point may be mentioned in connection with Mr. Pirrie's adoption and advocacy of improvements as showing his progressive ideas, and that is the system of four-cylinder balanced engines which he took up some time ago after having satisfied himself of its advantages, and which he has applied in many steamers during the last few years with the most satisfactory results as to economical working and the reduction of vibration.

Mr. Pirrie, however, is not known only as a great shipbuilder; he has attained considerable success and eminence in public life, having been for two years (1896 and 1897) Lord Mayor of Belfast; High Sheriff of County Antrim in 1898; while this year he fills the office of High Sheriff of County Down. He was made a Privy Councillor about two years ago,—an honour that every one felt was thoroughly deserved and the conferring of which gave great satisfaction to his many friends and well wishers and the public of Belfast and neighbourhood, with whom he is extremely popular. Although pressed to retain the office of Lord Mayor for a third year, he relinquished the post at the end of '97, so as to have more time to look after the construction of the *Oceanic*. During his lord mayoralty he carried through many reforms, including a great extension of the city boundaries by which the area of Belfast was trebled, and the enlargement of the City Council.

His mayoralty was also noted for the celebration of the Diamond Jubilee in Belfast by the inauguration of a fund for a new hospital to be called The Royal Victoria Hospital. For this his accomplished wife, who is as popular as he is himself, and who proved an ideal Lady Mayoress, was mainly instrumental in raising over £100,000 within a few months, Mr. Pirrie (through his firm) and the Lady Mayoress having themselves led the way with very large subscriptions.

In the City Council and at the Harbour Board, of which he is also a member, he is recognised as an invaluable representative of the most progressive element of a progressive city. Before his term of office as Lord Mayor had expired Mr. Pirrie was entertained by his fellow citizens at a public banquet at which the Marquis of Dufferin and Ava presided, and when he retired from the lord mayoralty it was felt that the highest honour in the power of his fellow citizens to bestow should be conferred upon him, and accordingly he was made the first freeman of Belfast, the certificate of the freedom of the city being presented to him in a very handsome gold casket. Singularly enough the next name on the list of freemen will be Mr. Thomas H. Ismay, chairman of the White Star Line, upon whom the freedom of the city of Belfast has also just been conferred in connection with the launch of the *Oceanic*, and thus the owner and the builder of this leviathan will appear together on the scroll of fame.

Mr. Pirrie is a director of the Belfast and Northern Counties Railway, a Justice of the Peace for the city of Belfast, and also for County Antrim and for County Down; he is a governor of various local institutions and asylums, and is well known as a generous supporter of philanthropic and other movements and organisations; he is a member of the Reform Club, London, also of the City of London Club, the Kildare Street Club, Dublin; the Ulster Club, Belfast; a member of the Council of the Institution of Mechanical Engineers, a member of the Institution of Civil Engineers, the Institution of Naval Architects, and the Institute of Journalists.

During his term of office as Lord

Mayor, Belfast may be said to have been *en fête* the whole time; he seemed to entertain every one, from prince to peasant, having had a banqueting hall erected specially, adjoining his house at Ormiston, County Down, and his guests at different times included the Duke and Duchess of York, Their Excellencies the Lord Lieutenant of Ireland and the Countess Cadogan, the Marquis of Dufferin and Ava, the Marquis of Londonderry, the members of the Institution of Mechanical Engineers, the Institute of Journalists, the National Teachers' Association, the Booksellers' Union, the officers and men of the Channel Squadron, the General Assembly, and others. On the occasion of the visit of the Duke and Duchess of York Mr. Pirrie entertained 10,000 Sunday-school children at Ormiston to greet Their Royal Highnesses, as well as the Boys' Brigade, in another part of the city.

The Lord Lieutenant paid three official visits to Belfast while Mr. Pirrie was Lord Mayor, and his wife, the Countess Cadogan, performed the christening ceremony at the launch of the steamship *Goorkha*, in January, '97, a vessel built for the Union Line to South Africa. It may here be mentioned, however, that the christening ceremony is almost invariably dispensed with at Messrs. Harland & Wolff's, there being very few exceptions, such as in the case of the *Goorkha*, just mentioned, and the *Briton*, for the same line, christened by Lady Evans. Even at the launch of the *Oceanic* there was no ceremony whatever. The vessel received her name when the keel was laid, and when all was ready for launching the signal for her release was given and the mighty vessel glided into the water amid the cheers of tens of thousands of joyous onlookers without a drop of wine being spilt over her bows.

In politics Mr. Pirrie is very much what he is in everything else,—a man of strong views. He is a liberal unionist, but up to the present, though on many occasions Parliamentary honours have been within his grasp, he has resolutely declined them. While not laying any claim to oratorical gifts or powers, he is an interesting and effective speaker, and whether as a member of the House of Commons or of the Gilded Chamber, to which some of his friends think the recognition of his eminent public and national services will some day elevate him, he is likely to give a good account of himself.

Mr. Pirrie is one of those great engineers and employers that seem born to command, having larger ideas than others and a greater insight into men and things, besides an extraordinary power of organisation and a thorough grasp of the mechanical problems of the day; he is one of those men for whom nothing seems too big, no difficulty too great, and no task too stupendous, who develop industries and open up commerce and influence trade, sending the products of their brain and skill wide over the earth, and who not only benefit their own country, but advance engineering science and contribute most to that progress which is the characteristic feature of the age. It is only with such men as these, Lord Armstrong, of Great Britain; Krupp, of Germany, and Carnegie, of America, great leaders and captains of industry, that Mr. Pirrie can be compared.

Current Topics

One of the immediately striking differences between British and American and Continental electric railway practice is afforded by the ways in which the current is carried from the overhead conductors to the cars. In both Great Britain and the United States roller contact is exclusively used, nearly always in the shape of the familiar small trolley wheel, though in a few instances, as, for example, on the Douglas and Laxey Coast Railway, in the Isle of Man, this wheel has been abandoned in favour of a roller of considerable width, or perhaps length would better express it. On the continent of Europe, on the other hand, a sliding bow is employed, and the trolley wheel, as we know it, is symbolical of crudity in practice. A few years ago the bow was made of iron, and considerable pressure was required to make good contact; then an improved bow was brought out, made of brass covered with white metal; and after this came a bow of aluminium with a longitudinal groove at the top, filled with fat. This was intended to do away with the scraping noise made by the earlier devices. The life of a brass bow covered with white metal is said to be about two weeks, while the aluminium bow lasts from six to eight weeks. The maintenance cost of both the types of bow is practically the same, and is given as about 0.013d. per car-mile. The contact pressure on the wire should be only just sufficient to prevent sparking, and, according to a Dresden by-law, must not exceed 7.7 pounds, and is usually below it. It has generally been supposed that the bow contact wears the wire out more rapidly than the roller, but this has been claimed to be erroneous, as the bow is said to wear a flat on the wire at the bottom only, while the roller wears it at the sides also, especially on curves.

Of the achievements in metallurgy which have either been actually effected or are in immediate prospect Professor Sir W. Roberts-Austen recently gave the following collective statement in his presidential address to the Iron and Steel Institute of Great Britain. There are, he said, blast furnaces which will produce 690 tons of pig iron in 24 hours, with a consumption of little over 15.4 cwts. of coke per ton of iron, and the gases from blast-furnaces are used not only as sources of heat, but directly in gas-engines. There are Bessemer converters which can hold 50 tons of metal, and open-hearth furnaces which will also take 50 tons, while 100-ton furnaces are projected. The open-hearth furnaces are fed with one ton of material in a minute, by the aid of a large spoon worked by an electro-motor. There are gigantic "mixers," capable

of holding 200 tons of pig iron, in which, moreover, a certain amount of preliminary purification is effected. Steel plates are rolled of over 300 feet in area and 2 inches thick, and there are girders which justify the belief of Sir Benjamin Baker, that a bridge connecting England and France could be built over the Channel in half-mile spans. There are ship-plates which buckle up during a collision, but remain water-tight. There are steel armour-piercing shot which will penetrate a thickness of steel equivalent to over 37 inches of wrought iron. The points of the shot remain intact, although the striking velocities are nearly 2800 feet a second. There are wires which will sustain a load of 170 tons per square inch without fracture. Hadfield, whose labours he hoped to see continued far into the twentieth century, has given us manganese-steel that will not soften by annealing; while Guillaume has studied the properties of certain nickel-steels that will not expand by heat, and others that contract when heated and expand when cooled. Nickel, chromium, titanium, and tungsten are freely used alloyed with iron, and the use of vanadium, uranium, molybdenum, and even glucinium, is suggested. Huge ingots are placed in soaking pits and forged direct by 120-ton hammers, or pressed into shape by 14,000-ton presses, and there are steel castings for parts of ships that weigh over 35 tons.

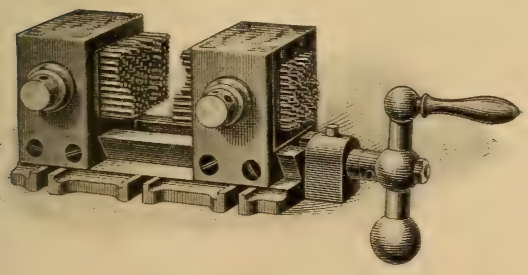
WITH the spectre of electrolysis hovering over electric railway enterprise, there ought to be some crumbs of comfort for railway managers and gas and water works officials in the recently expressed thought that glass will be the material of the future for such things as gas and water and other underground pipes upon whose life serious attacks have, in the past, been made by leakage from electric rail returns. Indeed, the prediction has been made that in a brief half-dozen years or so, cast and wrought-iron pipe will be hopelessly out of date, and anxiety over their electrolytic corrosion will no longer cause sleepless nights to any one. Glass pipes themselves are not altogether novelties. In a relatively small way they have been used with encouraging results, and it does not now seem so very visionary to speak of them as the coming pipes for city use.

THE principle of the evaporative surface condenser has been turned to a new account in an apparatus brought out in the United States by what is known as Bell's House-Cooling Company, of New York, and intended, as this name implies, for the cooling of buildings,—dwellings, offices and the like. Instead, however, of cooling steam, as does the familiar condenser, the apparatus, which, by the way, has been devised by Dr. Louis Bell, of electrical repute, cools air, and this is discharged into the room containing the outfit, passing and repassing through the cooling ducts and helping to maintain, in this way, a temperature from 10 to 25 degrees lower than the original temperature of the air. The water which is used is allowed to trickle over a thin copper septum wall disposed in the cooling flues, and the air blast for these and for the rapid evaporation comes from a small electrically-driven blower, which, in one of the machines thus far constructed, has been found to deliver about 10,000 cubic feet of air per hour through the machine with an expenditure of about 100 watts. A few quarts of water per hour have proved sufficient to keep this air at a very comfortable temperature, and the whole cost of operation, added to the rental for the machines, which latter are not sold to the users, would seem well worth incurring for the results obtained.

AN interesting but little known bit of history in connection with early steam navigation on the ocean was brought to public attention in the recent address of the venerable Kivas Tully on his election to the presidency of the lately organised Engineers' Club, of Toronto. This,

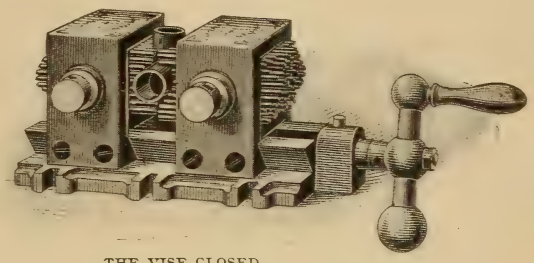
according to *Engineering News*, was to the effect that to the Province of Quebec belongs the credit of having built the first steamship that crossed the Atlantic from either side. The steamship was called the *Royal William*, commanded by Captain McDougall, and sailed from Quebec on August 5, 1833, arriving at Gravesend on September 11, having steamed the whole distance. This seems at first sight to contradict the well-known claims to priority made for the *Savannah* as the first steamship to cross the Atlantic. The *Savannah*, however, on her memorable voyage from Savannah to Liverpool (May 26, 1819, to June 20, 1819) used her engines during eighteen days and progressed under sail the remainder of the time, the paddle-wheels being hoisted on board when not in use. The *Royal William*, therefore, appears to have been the first vessel to make the voyage using steam for the whole distance. It was not until five years after the voyage of the *Royal William*, however, that regular steam navigation across the Atlantic was established by the voyages of the *Sirius* and the *Great Western*.

Among time and money-saving devices for the machine shop one of the neatest little contrivances of recent date is the vise for holding irregular work shown in the two illustrations on this page, which have been reproduced from *The Engineer*, of London. The type



A VISE FOR IRREGULAR WORK

shown is intended principally for bolting to the table of a drilling machine, but other designs suitable for a lathe chuck and for an ordinary bench vise are in hand. The vise consists of two frames or boxes which slide on a well-proportioned rest, and are moved by a right and left-hand screw rotated by a handle. Each box is completely filled with a large number of small hexagon mild



THE VISE CLOSED

steel pins, the ends of which are reduced so as to leave a shoulder and to act as a guide. On each one there fits a small spiral spring, which, by pressing against the shoulder of the hexagonal part and against a back plate through which the shanks pass, drives the pin forward. On account of their shape the pins all pack together into the box or frame like a honeycomb. In each box there is a clamping plate and screw. If it is desired to drill out such a piece as one of the steel tees or elbows used in bicycle construction, a cleaned-up but unmachined casting of one is taken and is driven fairly tight onto a drill or spindle fixed in the drilling machine. The vise is then brought into position under it, the clamping screws are loosened, and the handle is turned so that the casting is pressed between the jaws. It is evident that an impress of each half of the casting will be left on the flexible faces of the vise, some of the bars projecting further than others, according to the shape of the piece, and if the jaws are then clamped up while the piece is in position, a rigid mould will be left, and a jig formed with little trouble and in little time. The vise is made by E. Henry Jones, Clerkenwell Road, London, and is recommended as a strong and well-made tool.

An interesting example of scale formation in a steam boiler was afforded

by one of the smaller vessels of the United States Navy after several months' service on the Cuban blockade last year during the Spanish-American war. The boiler in question was one of Yarrow's, a water-tube boiler consisting, as is pretty generally known, of a steam drum to which two banks of straight tubes are attached, one of which extends obliquely downward on either side of the fire. The upper ends of these tubes are expanded into the steam drum, and the lower ends of each bank are similarly expanded into a practically flat plate which forms the cover of a kind of water chamber or mud drum. In this particular boiler copper tubes were employed, one inch in diameter, and set so closely in staggered rows that it was scarcely possible to see between the rows in either direction. In the course of repairs it was thought desirable to renew some (or all) of the tubes, and when they were taken out it was found that they were considerably pitted and corroded on the outside, so that in a number of places the tubes were entirely perforated. In the case of one of the tubes corrosion had been so active that 5 inches of the tube's length were entirely gone and the free ends were worn down to the thinness of paper. Despite the extent of the corrosion the engineer in charge of these boilers was unaware of the existence of any serious defect in them, although he had steamed into port with a pressure of 240 pounds to the square inch, the spaces between the tubes being so solidly obstructed by a stony scale, in the vicinity of the break, that no leakage was remarked. To these particulars, which have been taken from *The Locomotive*, that publication adds that marine boilers of this type are supposed to be run wholly with pure, fresh water, for the production of which an adequate distilling apparatus is supposed to be provided. Yet it is a fact that salt water is often pumped into them directly, either because of a temporary shortness of the supply of fresh water, or for some other reason. As a consequence of this, it is no uncommon thing for the tubes to become coated, on the inside, with a deposit of sea salt, which may cause them to become overheated and burned. A small crack or other opening is then liable to appear, or perhaps the tube-ends spring a-leak, and the saline contents of the boiler ooze out. The sea-salt, thus carried to the outside of the tubes, is deposited upon them, mingled, doubtless, with a certain proportion of soot and ashes, and the solid matter so formed goes on accumulating until it may plug up the fire-spaces so thoroughly, in the vicinity of the leak, that further leakage is impossible. In the present case the action was probably quite similar, except that the wasted tube, to all appearances, was not encrusted on the inside. The initial leak probably came from one of the expanded tube-ends, or else from one of the pits that have perforated it from the outside in various places. The scale between the tubes was quite hard and stony.

THE copper mines of Sinai are stated in *Comptes Rendus* to be the most ancient of which history makes mention. According to authentic documents, they were worked from about 5000 years B. C., until about 1300 or 1200 B. C. Their possession had been the object of several wars, but they had been abandoned for 3000 years, on account of the poverty of the ores. It was from these mines that was obtained the sceptre of Pepi I., a king of the Sixth dynasty. This sceptre, made of pure copper, is preserved in the British Museum. The adits still exist, as well as the ruins of the furnaces, the crucibles, the huts of the miners, and some fragments of their tools. In some of the specimens obtained there occur three ores, turquoise, copper hydrosilicate, and sandstones impregnated with copper. Among the débris have been found remains of furnaces and crucibles, slags and cinders, fragments of tools. Nor is there evidence of the use of fluxes. Some of the fragments of tools contain arsenic, which was used by the Greek and Egyptian alchemists for hardening copper. It is interesting to note that metallurgical procedures similar to those of our days had been reached empirically 7000 years ago.

PHOTO BY DABBS, PITTSBURGH

H. C. Frick

(See Page 706)

CASSIER'S MAGAZINE

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THE LAKE SUPERIOR IRON ORE MINES

THEIR INFLUENCE UPON THE PRODUCTION OF IRON AND STEEL

By Jeremiah Head and Archibald P. Head

The matter given in the following pages was originally presented in the form of a paper at a recent meeting of the British Institution of Civil Engineers. Through the kind co-operation of Mr. Archibald P. Head, however, it was made possible to reprint it here, together with special reproductions from a large collection of photographs, made by the authors during their American tour of inspection. It is, in all, probably the most comprehensive paper on the subject that has yet appeared.—THE EDITOR.

UNDER the tariff law now in operation in the United States a duty of $4 (16s. 6d.) per ton* is payable on foreign pig-iron, $7.84 (£1 12s. 3d.) on steel rails, and $13.44 (£2 15s. 3d.) on steel ship-plates imported into that country. When the duties were first imposed, their amounts were those deemed necessary to secure the home market to American producers, and they may therefore be considered the measure of the advantage which the best situated foreign producers were then supposed to possess over their best situated American competitors. An export trade by American producers was not then considered possible.

These conditions have changed during the last few years, and a high tariff is no longer necessary for the purposes of exclusion of the imports referred to.

*The ton of 2240 lbs. is used throughout this paper.

In the period 1895 to 1898 the United States exports to the United Kingdom included the following items, viz:—

	1895 Tons	1896 Tons	1897 Tons	1898 Tons
Pig iron	3,668	17,417	91,196	†50,121
Unwrought steel	59	1,974	25,927	29,870

Steel rails and steel plates from the United States have also recently made their appearance in the United Kingdom, but as yet not in any very great quantity.

The first-mentioned item in the above table represents almost exclusively phosphoric pig-iron from Birmingham, Alabama. It has hitherto been used for foundry and puddling purposes, and is sent as ballast at low rates to cotton-receiving ports, during the cotton exporting season only. Latterly a special quality, cast in chills, has been exported for steel making in basic open-hearth furnaces.

Unwrought steel, which is now competing severely with the similar British product, emanates exclusively from the Northern States. As in the case of rails, plates, and structural shapes, it is

†The returns for the first ten months only of 1898 being available when this paper was written, one-fifth has been added to complete the estimate for the year.

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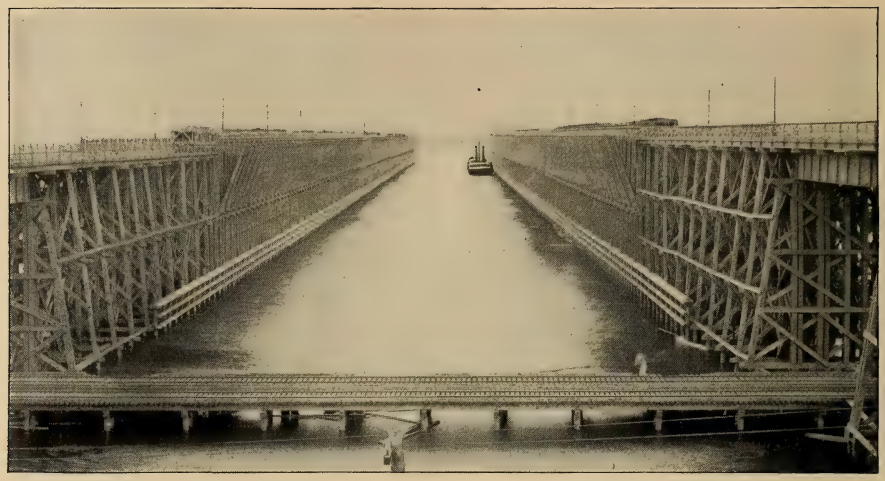


THE ORE DOCKS AT DULUTH, MINN.

made by the Bessemer and open-hearth processes, with pig-iron smelted from Lake Superior ores. The circumstances that the ores are brought an average of 800 miles to the furnace where they are smelted, and that they have displaced almost entirely the poorer local ores, for the utilisation of which the Northern iron trade was originally established, is of itself evidence of their richness, purity, and cheapness.

The recent unexpected invasion by American competitors of markets which had hitherto been considered exclusively British has naturally somewhat disturbed home producers, among whom there are those who question the allegation that the mineral resources of American iron and steel masters are superior to those available here. They believe that the new competition is carried on at a loss, and will never attain serious dimensions, but there are others who consider it permanent, and certainly the preparations and extensions undertaken in the United States provide evidence at least that the Americans have the courage of their convictions.

With the object of satisfying themselves on this question, which appears to be one of almost national importance, the authors decided early in June, 1898, to visit the Lake Superior region and to investigate some of the principal mines, the ores obtained from them, the routes by which they are carried southward to the blast-furnaces, and the means employed for mining, loading, unloading, and transporting them. The results of this investigation are given in this paper.

The principal iron-ore districts, or "ranges," as they are there called, of the Lake Superior region, are five in number, viz.:—

The Marquette, in the State of Michigan.

The Menominee, in the State of Michigan.

The Gogebic, partly in Michigan, and partly in the State of Wisconsin.

The Vermilion, in the State of Minnesota.

The Mesabi, in the State of Minnesota.

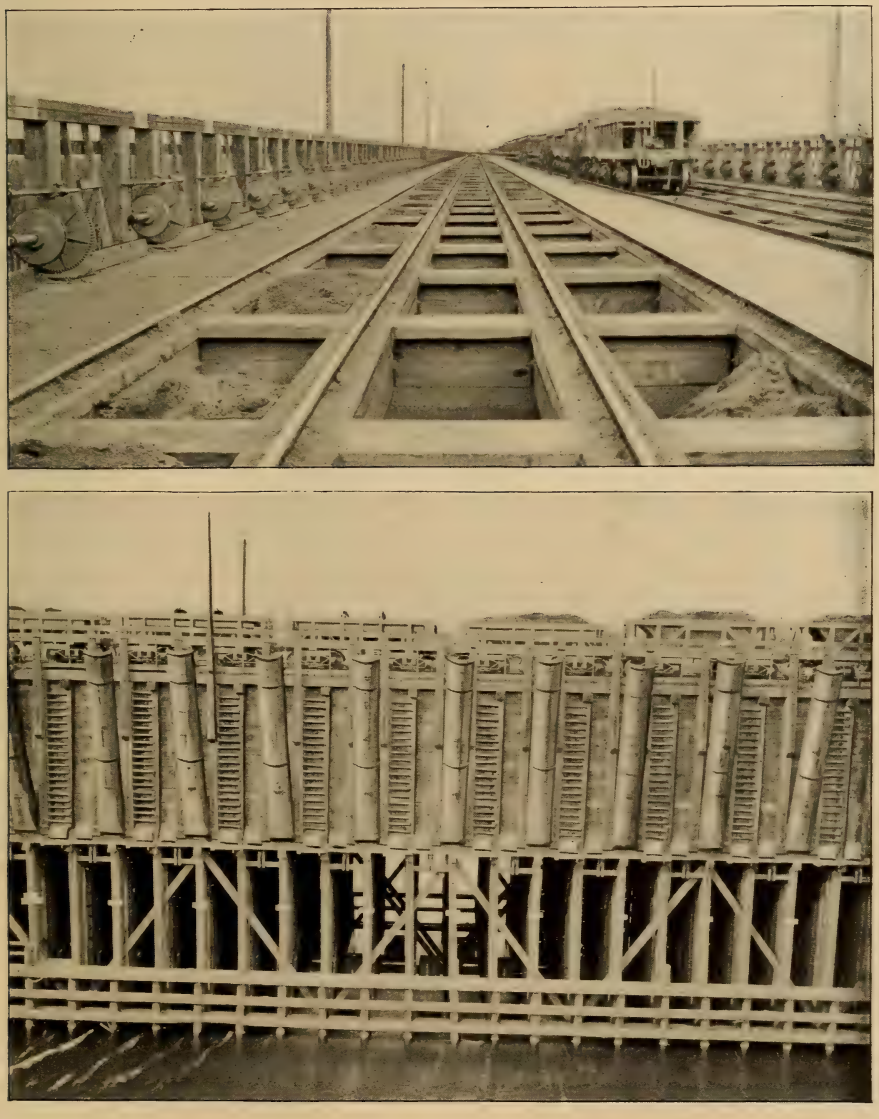
The Marquette Range.—The first discovery of iron ore in the Marquette range was made in 1844 by Mr. W. A. Burt, who, under the direction of Dr. Douglas Houghton, U. S. Surveyor, was completing the geological survey of the district. When near Teal Lake he found a remarkable variation of the compass needle, which led to a search and discovery of outcrops.

In 1845 the Jackson Iron Company was established to work the ore, and two years later a small local forge was

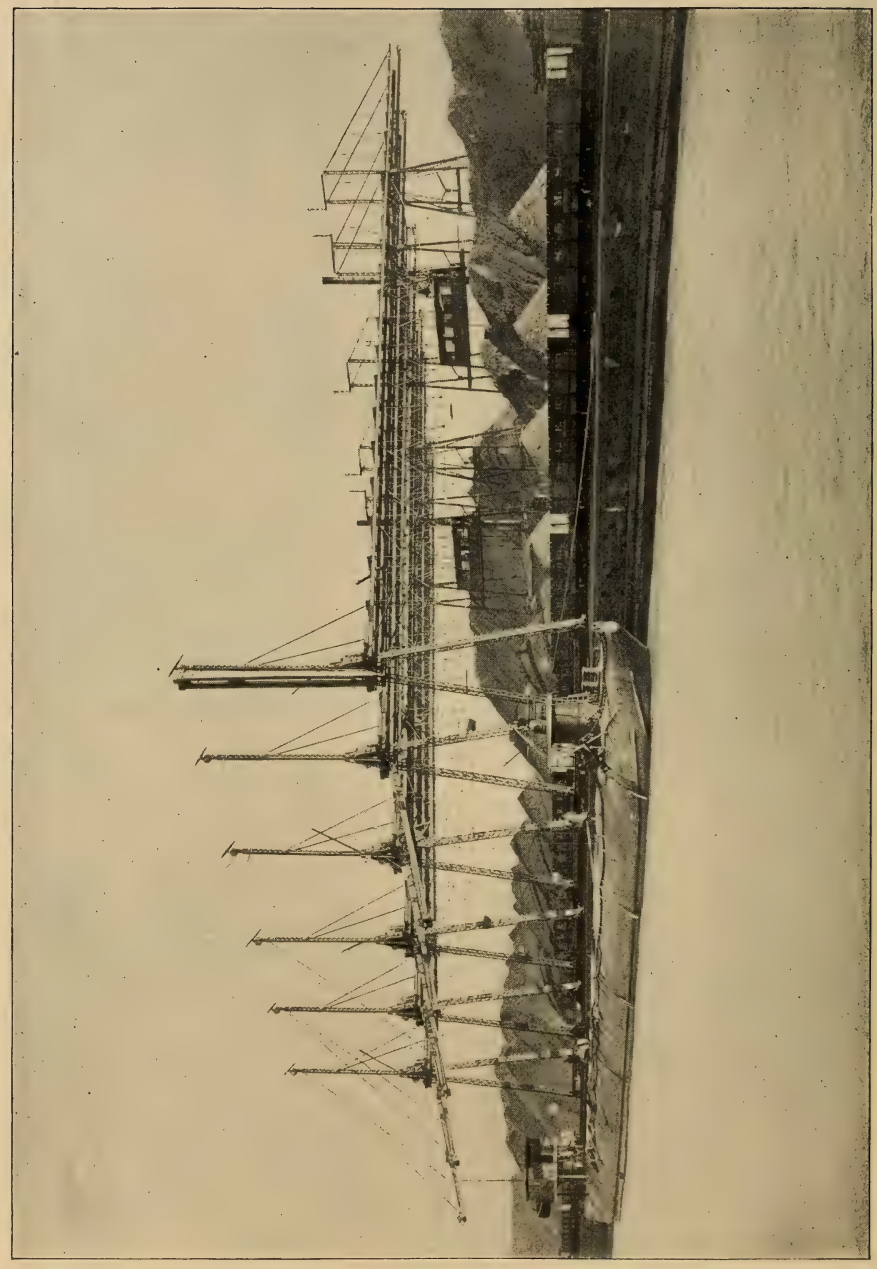
erected, but it was not until 1856 that as much as 5000 tons were shipped to the furnaces in Pennsylvania. When the Civil War broke out in 1861, the great demand for iron which suddenly took place led to considerable development, and to the building of prosperous cities such as the present Ishpeming.

The Menominee Range.—The discovery of iron in the Menominee range was made by Messrs. J. W. Foster and S. W. Hill in 1848, but no systematic exploration was attempted until, in 1872, Dr. N. P. Hulst was sent by the Milwaukee Iron Company for that purpose. In 1877 the Menominee Iron Company, of which he was a member, bought out the Milwaukee Company. The first shipments of ore were made at Escanaba in 1880, and the development of the district proceeded steadily thereafter.

The Gogebic Range.—In the Gogebic district ore was first discovered in



TOP AND FRONT VIEWS OF THE DOCKS



UNLOADING ORE FROM A WHALEBACK STEAMER DIRECT TO STOCK PILES AT CLEVELAND, OHIO

1848 by Dr. Randall, assistant to Dr. D. D. Owens, who was entrusted with the geological survey of Wisconsin. The occurrence was fully described in a report published in 1852 by Dr. Owens. It was said to be in the form of a stratified ore belt about 300 yards wide, dipping to the northwest, with its outcrop appearing along the summit of a mountain range. The Gogebic ore beds consist for the most part of hard brown hematite, and contain also a little red ore, and they are said to be practically inexhaustible.

In 1880 large deposits of soft brown ore were found by Captain N. D. Moore, and were shipped by him and others at Milwaukee, and thence transported by lake steamers to Erie city. This good fortune was quickly followed by the discovery and development of many other mines, and the shipment of ore in immense quantities.

The Vermilion Range.—The discovery of the Vermilion iron-ore deposits was first announced in 1866 by Mr. H. H. Eames, State Geologist. He described it as yielding rich magnetite and red hematite ores. No commencement was made to work it till 1875, and no great development took place until, in 1884, the Duluth and Iron Range Railway was made. Two years later it passed into the hands of the Minnesota Iron Company, under whose general manager, Mr. D. H. Bacon, additional discoveries were made, the best modern appliances were brought to bear, and the mines rapidly developed.

The Mesabi Range.—The district which remains to be described is perhaps the most remarkable. In 1850 Mr. J. G. Norwood noticed the occurrence of iron ore at the eastern end of a range of hills in Minnesota, called Mesabi, of which the western end touches the Mississippi River. But he does not seem to have considered the deposit of great commercial importance. Sixteen years later, Mr. H. H. Eames wrote an account of the same deposit, and submitted analyses showing that it yielded excellent ore. He even took steps to acquire the property, and made preparations to work it; but there operations ended for the time. Between 1866 and 1891, however, its value became gradually recognised by several persons, including Messrs. N. H. Winchell and A. Chester; and in the last-named year, the State authorities were repeatedly urged to promote its development. It was even then prophesied that it would one day yield greater quantities of rich ore than had ever been produced from any other range in the Lake Superior region. This prophecy has already been fulfilled; for the Mesabi range has now for some years held the record over all competing districts for large production. In 1890 the Mountain Iron Mine was discovered, and in 1891 the Biwabik group was opened out. Messrs. Merritt Brothers, of Duluth, were the first and most energetic explorers, and to them is mainly due the credit of the rapid development of the range. In 1892 the railway connection was improved, to give access by two routes, and to afford facilities for shipment either at Duluth or Two Harbours.

The following table gives the principal Lake Superior mining ranges, the year when mining was commenced, the output during 1897, and the total output from the commencement:—

Range	Year of Commencement	Outputs for 1897 Tons	Total Outputs to December 31, 1897 Tons
Marquette	1856	2,715,035	49,253,222
Menominee	1880	1,937,013	24,931,441
Gogebic	1884	2,258,236	23,047,023
Vermilion	1884	1,278,481	10,498,716
Mesabi	1892	4,280,873	12,345,456
Other mines	----	--------	2,320
Total		12,469,638*	120,088,178†

*The outputs for 1898 reached a total of about 14,200,000 tons, which increased the aggregate figure (†) to 134,288,178 tons.

Lake Superior is about 400 miles in length, by 200 miles in greatest width. The level of the water is about 602 feet above mean sea-level, and the maximum depth is 1000 feet, or 398 feet below sea-level. The hills and ranges, near

A WINTER STOCK PILE AT THE CLEVELAND LAKE MINE

the summits of which the ore deposits are found, vary in altitude above the level of the lake between 1000 feet and 1600 feet. The mines are all situated within 100 miles of the shore, so that the conditions are favourable to cheap railway transit and shipment. The distances from the ore shipping places on Lake Superior and Michigan to the ore-receiving ports on Lake Erie, vary between about 509 miles and 925 miles, and the distances from these ports to the principal ore-consuming centres range from nothing to 350 miles.

The authors do not propose to consider deeply the geological conditions under which the Lake Superior ores are found. The area over which they occur is wide, and it is far from having been fully explored. There are also without doubt other deposits in the same region, of which little is yet known. The specimens exhibited show that the ore exists in several distinct forms, due to difference of origin or difference in development. Almost all are hematites, either anhydrous (specular), or hydrated (limonite). The only magnetite in the whole region is that found, in small quantity, mixed with the Mesabi ores. Geological authorities are scarcely yet agreed on all points relative to the geological features of the region, or even as to the best nomenclature by which to describe them, but no doubt all difficulties of this kind will gradually disappear.

It will be sufficient for the present purpose to state that the ore deposits usually lie on a bed-rock of diorite or of quartzite, below which is green schist or granite. Above the ore there usu ally occurs surface drift in the Minnesota mines, and blue or black slate in those of Michigan and Wisconsin. The ore and the rocks containing it lie at various angles from the horizontal to the vertical, and dip under the lake on both sides of it. No organic remains have as yet been discovered in the deposits or in the surrounding rocks, except a few doubtful specimens.

The mining systems in vogue are four in number, viz., overhead stoping, caving, milling, and steam-shovelling. The last-named method is applicable to the

Mesabi district only. The other districts are worked by one or more of the three first-named methods.

In the overhead-stoping method, Fig. 1, a slanting shaft of oblong section is sunk in the foot-rock following the dip. It is frequently partitioned into a winding and pumping-shaft and a ladder way. The cross-section of the shaft in one case measured by the authors was 21 feet by 7 feet. It was 1000 feet deep, and was lined with timber throughout. From the shaft, at a depth of about 62 feet below the surface of the ore the first heading is driven horizontally across the deposit and is timbered. From this another heading is driven longitudinally along the centre of the deposit for a distance of 24 feet and also timbered. The ore is then worked out sideways and upwards, and is allowed to fall to the original cross level, whence it is conveyed to the shaft. The workings are followed by timber scaffolding until the surface soil is reached, and a mass of ore 62 feet high, 24 feet long of the entire width of the deposit has been removed. Leaving a pillar of ore of the same length, the central road is carried forward, and the ore is worked out for another 24-foot length, and the cavity is supported as before. When complete the timber is made to collapse by aid of dynamite, which usually leaves a deep hole, owing to falling in of the surface.

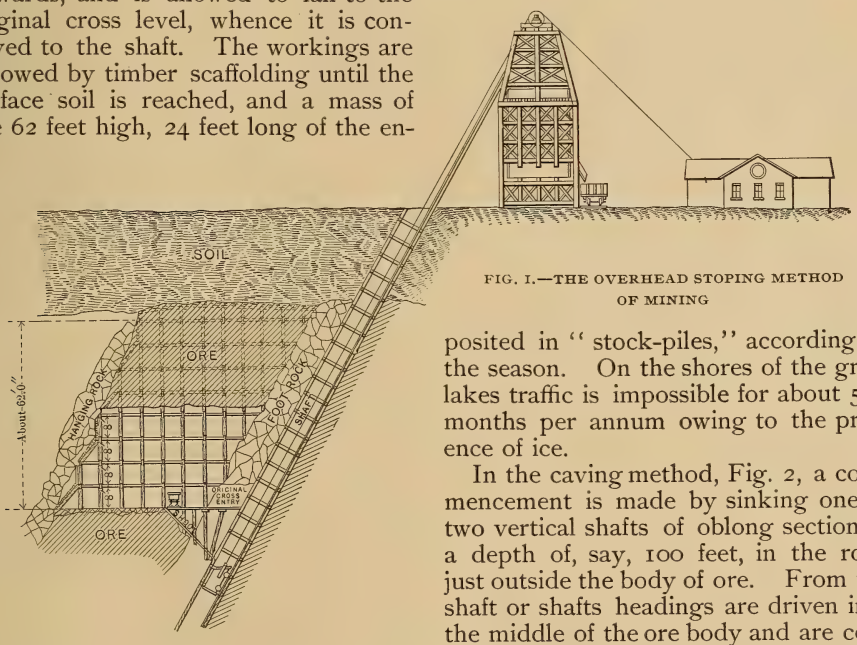


FIG. 1.—THE OVERHEAD STOPING METHOD OF MINING

The intermediate pillar is then worked out by the "caving" system. No attempt is made to recover the timber. The shaft is then continued downward far enough for another 63-foot slice to be worked out, and so on. There are stoping mines where no timbering is necessary; in such cases the excavations are filled with sand or rubbish as they are worked out.

The winding-skips, of which there may be only one or two alternately working in each shaft, are made of steel plates, and hold between 3 tons and 6 tons of ore. They are wound to the top of the head gear, and are there tipped automatically, the contents falling into bins or through them into waggons. In these the ore is presently taken to the shipping docks, or is deposited in "stock-piles," according to the season. On the shores of the great lakes traffic is impossible for about 5½ months per annum owing to the presence of ice.

In the caving method, Fig. 2, a commencement is made by sinking one or two vertical shafts of oblong section to a depth of, say, 100 feet, in the rock just outside the body of ore. From the shaft or shafts headings are driven into the middle of the ore body and are connected by a longitudinal roadway. At 25-foot intervals, on both sides of this main road, timbered rises, 7 feet by 3 feet 6 inches, are worked upwards. They comprise a through shaft or shoot, and a ladder-way. The rises are carried up to within 7 feet of the top of the ore body, and are then connected longitudinally for ventilation. The side passages are driven to the edge of the ore,

which is worked out between the passages, the roof being temporarily supported by props. In this way a horizontal slice, 7 feet thick, is excavated under the surface soil. When the props show signs of distress they are blasted away, and the surface is allowed to fall in to that extent; but the floor is first covered with rough timber so as to provide a good roof for the next slice, which is then attacked in a similar way. The ore is all passed down the shoots into tubs in the main road below and thence to the shaft and to bank. As the ore is worked out, the surface of the ground gradually caves in until an immense pit is formed. The overhead-stoping method is being gradually supplanted by the caving system. In the former, where so much timber is left standing, the miners do not feel absolutely secure, either overhead or under foot. In the caving system the floor is always solid, and the roof never falls more than 7 feet at a time. The caving system costs for timber about 2½d. per ton of ore worked. The stoping method requires more and larger-sized timber, and therefore is more costly in both ways.

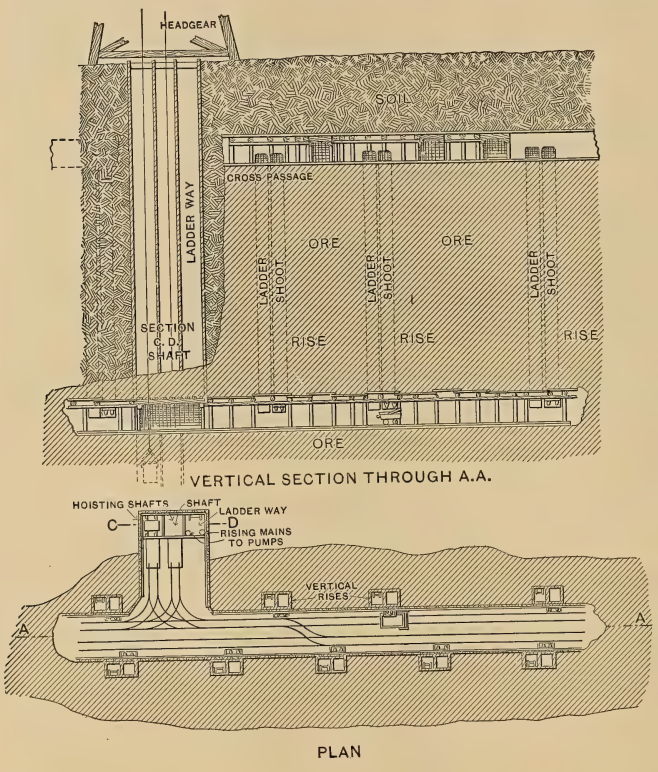


FIG. 2.—THE CAVING METHOD

The milling method, Fig. 3, is somewhat similar to that last described. A shaft, generally vertical, is sunk outside of, but as near as possible to, the ore deposit. At a depth of, say, 60 feet, a heading is driven to the centre of the ore body, and another along it. From this heading side drifts are made right and left until rock is reached. Upward, from the main and side drifts, rises are cut to the surface of the ore, and are lined with timber, and furnished at the bottom with spouts and doors for filling the tubs. The surface soil is removed till the top of the ore body is laid bare. Then the ore is dug out and is shovelled down the rises into the tubs below, to be afterwards wound up the main shaft and disposed of as before. Milling is resorted to in preference to caving wherever the ore body is found close to the surface. It has the advantage that less timber is required, and that the chief operations are carried on in the open air.

By far the best and cheapest of the four mining methods is that by open-cut with steam-shovels. This has so far proved applicable only to five mines, which are all in the Mesabi district, viz., the Mountain, Oliver, Ohio, Mahoning and Biwabik mines. The physical condition of the ore here resembles earth rather than rock. It lies on the slopes of the hills in immense masses with little soil above it. The steam-shovels used are similar to those known in Great

Britain as "steam navvies," but are larger and more powerful. Those of the most modern type have three separate pairs of cylinders and one boiler. They weigh 92 tons, and cost about £1900 each. They are carried on four axles. One machine has filled two hundred and thirty-two 25-ton ore waggons, or a total of 5825 tons, in 9 hours, but this is a record performance. Five tons of ore can be lifted by the machine each stroke, and five full-weight lifts will fill a waggon. The authors watched a 25-ton waggon filled in 2½ minutes by seven bucketfuls, which is at the rate of 600 tons per hour. Ten men, exclusive of the trainmen, are required to work the machine, which consumes about 4 cwt. of coal per hour.

The Mountain Iron Mine, a typical open-cut mine, which was visited by the authors, is half a mile long by 1200 feet broad, and at present 85 feet deep (Fig. 4). It is worked in horizontal slices of 20 feet, the vertical range of the steam-shovel. Removal of the surface soil as required is also performed by the machine. The average thickness of covering is here 27 feet. The mine is drained by a central longitudinal cut, at the lowest part of which are a gasoline engine and a pump. The cut is deepened as the excavation proceeds.

A certain amount of blasting is necessary at the "shovel" mines to loosen the soil and ore, and thus facilitate the work of the machine. Holes 1¼ inches in diameter are made by driving in pointed steel bars to a depth of 20 feet. These are opened out at the bottom by the explosion of small dynamite charges. Between 25 pounds and 75 pounds of black powder are then poured in, tamped and exploded. Fig. 5 shows an ingenious double-claw gripping-tool for drawing out the boring bar when required.

A train of ten to twelve 25-ton waggons is run alongside a steam-shovel, and is worked forward by a locomotive as fast as the waggons are filled. It is then drawn out, sorted, and made up into longer trains for transport to the

THE CAVING SYSTEM AT FRANKLIN MINE, IN THE MESABI DISTRICT

docks. These trains usually consist of forty-four waggons, whether full or empty. Whilst one engine is attending a steam-shovel, another is preparing a set of empties to replace those drawn out full. In this way the work is almost continuous.

The Mesabi ores, being exceedingly rich and pure, are obtainable (according to Mr. H. V. Winchell) at 10d. per ton free on the waggons, including all costs; the other districts, where the ores are worked by more expensive methods, costing as much in some cases as 4s. 2d. per ton on trucks, could no longer compete, but for the fact that on account of its pulverised condition smelters cannot use Mesabi ore in a greater ratio than 30 per cent. to 40 per cent. of the charge. To this circumstance is due the continued demand for the other ores, even at considerably higher prices than the Mesabi products can be obtained for. Nevertheless, it is probable that, but for the Mesabi competition, 20s. per ton at Pittsburgh would still be the price of Lake Superior Bessemer ores, instead of a little more than half that price.

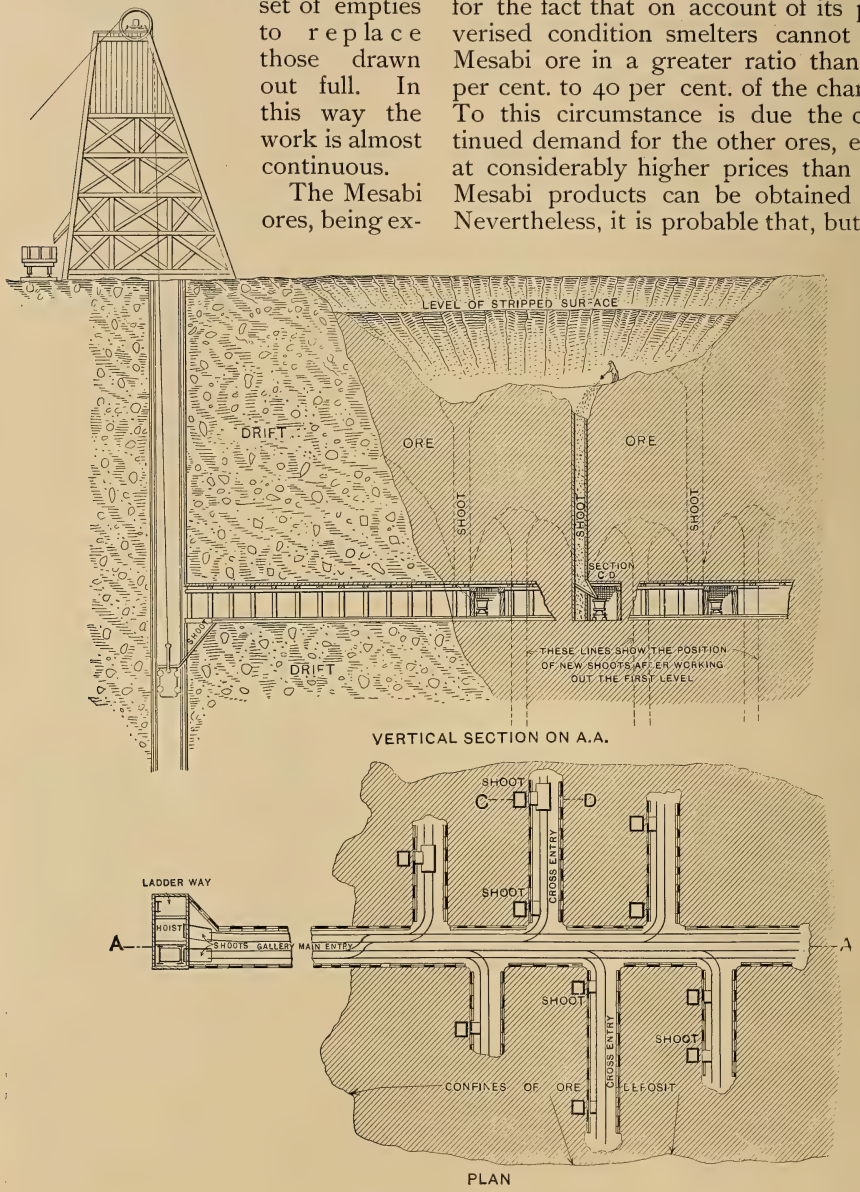
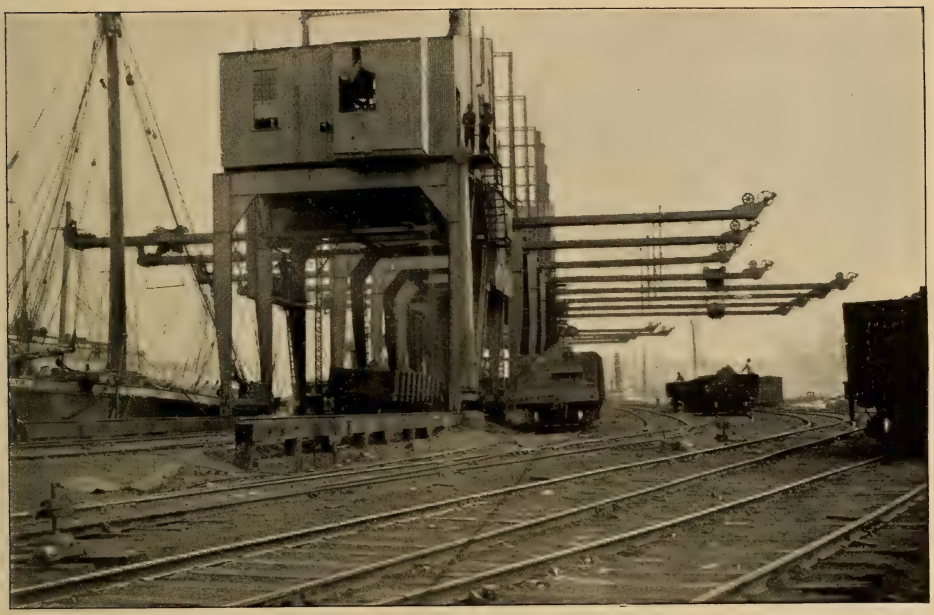


FIG. 3.—THE MILLING METHOD



UNLOADING ORE DIRECT FROM VESSELS TO CARS

In the Marquette district the Cliffs Shaft mine, at Ishpeming, may be mentioned as a good example. It belongs to the Cleveland Cliffs Iron Company, and is managed by Mr. H. H. Duncan. It is worked by the overhead-stoping method, but on account of the hardness of the ore and enclosing rock no timbering is necessary. There are two vertical shafts, one 575 feet and the other 400 feet deep. Both are used as pumping and winding-shafts. The water to be dealt with amounts to about 400 gallons per minute. Rand rock-drills are in use below in getting the ore, and a 50 per cent. mixture of dynamite is employed as the explosive. The ore, on being brought to bank, is all passed through Blake crushers, two of which deal with the entire present output, viz., 1000 tons per day, and could do half as much again. The maximum size of the lumps here crushed is 24 inches by 18 inches, but at some mines 30-inch by 30-inch lumps are dealt with. From the crushers the ore falls into 30-ton main-line waggons, in which it is taken by locomotives 15 miles to the shipping docks at Marquette harbour, at a cost of 1s. 4d. per ton.

In the same district there are some soft-ore mines, the shafts of which are mostly on the brink of an ancient lake. One of these mines is 380 feet deep, and is worked below by electric haulage. Steam-shovels are used to load the stock-piles, which accumulate in winter, into waggons for shipment during the following summer. The average extra cost of putting into stock, holding 5½ months, during which navigation is closed, and reloading, is said to be 3d. per ton. The Marquette mines are all held in fee simple, and are not subject to any royalty on their product. About 50 per cent. of the ore is of Bessemer quality, that is, it does not contain more than 0.045 per cent. of phosphorus.

In the Gogebic district, the Norrie mine at Ironwood may be described. It belongs to the Oliver Iron Mining Company, of which the Carnegie Steel Company and the Oliver Iron and Steel Company, of Pittsburgh, are the principal proprietors. It is managed by Mr. T. F. Cole. The ore is mostly

THE MILLING SYSTEM AT THE CLEVELAND LAKE MIN

brown hematite, but there is a little of the hard variety. The quality is very good and pure, 90 per cent. being fit for making Bessemer pig-iron. It is worked by the overhead-stoping system. It is all shipped at Ashland, a Lake Superior port, 32 miles distant, and is carried thence to Conneaut, *en route* for Pittsburgh by way of the new Pittsburgh and Lake Erie Railroad. The Norrie mine has several shafts at an angle of 62° with the vertical. Its average output is 1500 tons per day. The output statistics of the region seem to prove that the development of the Mesabi range has had a detrimental effect on the others, and especially on the Gogebic. The authors, in passing through the district, observed that a considerable number of mines appeared to be closed.

FIG. 4.—THE MOUNTAIN IRON MINE. A TYPICAL OPEN-CUT MINE

The Menominee mines possess special characteristics which may be mentioned. The ores are not so high in iron nor so low in phosphorus as those of other districts, but they are low in moisture, and they are the only ores which are self-fluxing. They are easy to work and are cheaply mined, whilst the royalty payable is only 3d. per ton. The railway freight to Escanaba, the shipping port, is 2s. per ton, and the lake freight thence to Lake Erie ports is 1s. per ton less than from more westerly points.

The mines in the Lake Superior districts, the railways to the docks, and the ore-docks are in the hands of many proprietors. But the tendency is for them to pass into the hands of a few individuals or companies possessing large capital and more than usual enterprise. Among these, the following may be mentioned:—(1) The Consolidated Iron Company, of Duluth, which is controlled by Mr. J. D. Rockefeller, as also is the Duluth, Mesabi and Northern Railway, the ore docks at Duluth, and the splendid modern ore steamers, known as the Bessemer fleet. Their mines are all in the Mesabi district. The Mountain Iron Mine, which has been referred to, belongs to this company, but is leased to the Carnegie Steel Company, which pays 1s. per ton royalty. Some other mines are let by them on lease, and some they work themselves. (2) The Minnesota Iron Company, which controls the other railway to the Mesabi range, called the "Duluth and Iron Range Railway," and the extensive ore-loading docks at Two Harbours, and another fleet of ore steamers. A large interest in this company is held by the Illinois Steel Company, of Chicago, now merged in the new "Federal Steel Company." (3) The Carnegie Steel Company, of Pittsburgh, which is associated with the Oliver Iron and Steel Company, of the same city, and which, as the Oliver Iron Mining Company, controls the Norrie Mine in the Gogebic district, and the Ohio, and the Mountain Iron Mines in the Mesabi range, and is otherwise allied with the Rockefeller group.

The two great rival interests in the Lake Superior region would seem to be at the moment that of Messrs. Carnegie and Rockefeller of the one part, and that of the Federal Steel combination of the other.

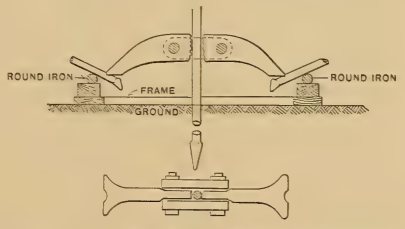
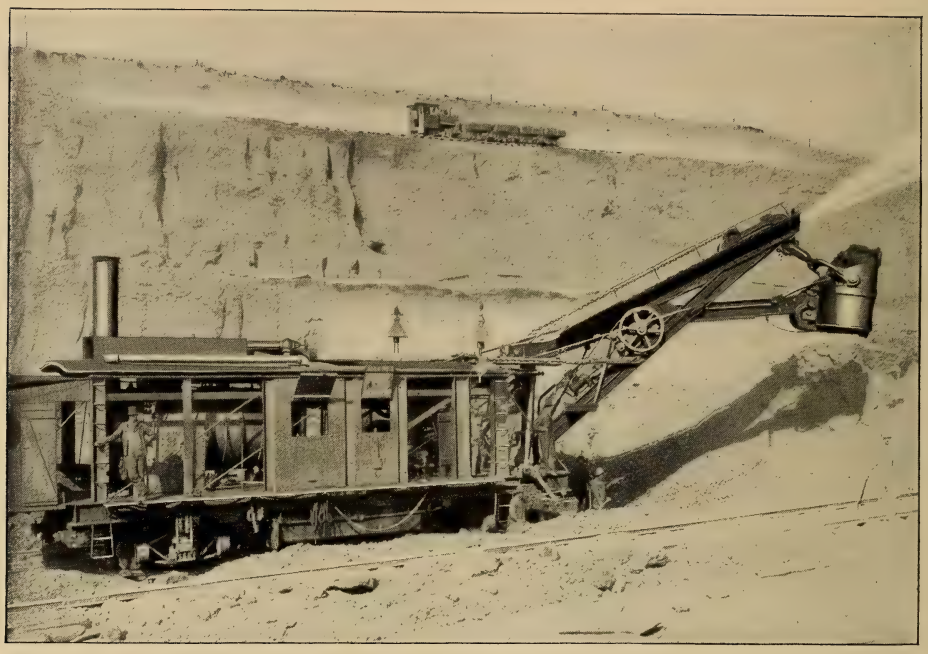


FIG. 5.—GRIP FOR WITHDRAWING BORING BAR

The railway rate by either route from the Mesabi range to the ore docks, a



A STEAM SHOVEL IN THE MESABI DISTRICT. BUILT BY THE VULCAN IRON WORKS COMPANY, TOLEDO, OHIO

distance of 75 miles, is 3s. 4d. per ton, or ½d. per ton-mile. This is not considered cheap, and is maintainable only because the traffic will bear it. The grade being with the load, the cost of haulage must be light and the lines very profitable.

Sampling and testing the ores so that their precise quality and value may be known and relied on in advance, is systematised in the United States in a perfect manner. The principal laboratory is at the shipping docks, but the results there obtained are checked by two tests made in the mines, viz., one for prospecting purposes, from the ore *in situ*, and the other from samples taken from the loaded waggons. At the ore docks, the analyses are made from 600-pound lots, made up of 4000 to 5000 samples, taken from the cars as they arrive. Only the iron, phosphorus, moisture and (sometimes) manganese are determined. The results are checked by fresh tests at Cleveland, or other receiving port. On the ore-dock analysis, so checked, the ores are bought and sold. In all sales and purchases of Lake Superior Bessemer ores it is assumed that they contain of iron 63 per cent., phosphorus 0.045 per cent., and moisture 10 per cent. If these constituents vary from the above-mentioned amounts, a corresponding allowance in price is made.

Spanish, Cumberland, and Lancashire hematite ores, upon which the British steel trade so largely depends, contain considerably less phosphorus than the Lake Superior ores. This is probably the reason why rails and other steel products of American Bessemer (acid) converters include more of that impurity than similar British products. In the manufacture of steel by the open-hearth process the Americans have surmounted the difficulty by the now almost universal employment of basic linings. Whether Bessemer or non-Bessemer pig-iron be used, the product is then equally pure. The sufficiency hitherto of the non-phosphoric ores of Spain accounts for the perhaps dangerous tardiness of most British steel makers in adopting basic-lined open-hearth furnaces, which would certainly help them

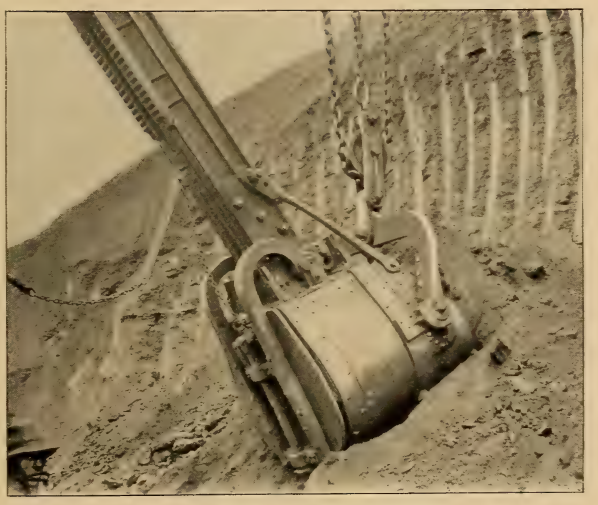
greatly to extend their sources of supply. The total capital now invested in the Lake Superior iron-mining industry has been estimated by Mr. H. N. Winchell at not less than £50,000,000. As to the duration of the supply of Lake Superior ores, the same high authority states, in respect of the ore ranges other than the Mesabi, that the day is yet far distant when the underground and hard-ore mines of this region will cease to respond to the demands of ever-widening civilisation and its ever-increasing use for iron.

And of the Mesabi range he states:—"When it was first developed miners and merchants of other districts comforted themselves with the vain hope that it was pockety, that its shallow mines would soon be exhausted, that its ores could be used only in small quantities in average mixtures, and so on. The facts are these:—There is more ore in sight to-day, three or four times over, than the whole Lake Superior region has produced in 50 years. Its deposits are deeper, wider, larger, and better than those of any other range. More of its ore has been used for some years past than of ore from any of the older ranges, and the disparity seems likely to become greater year by year.

"Active exploration dates back here but four seasons, and yet there are in sight to-day nearly 400,000,000 tons of ore, better in quality than the average used in the States, and perhaps 200,000,000 tons will average 60 per cent. of iron, 0.06 per cent. of phosphorus, and 10 per cent. of moisture, and the end is not yet. It is not by any means a wild prediction that the Mesabi range will produce 500,000,000 tons of iron ore before it is abandoned."

The aggregate production of ore by the Lake Superior mines was, in 1897, at the rate of about 12,500,000 tons per annum. Of this about 300,000 tons are locally smelted in furnaces using charcoal, no other fuel being there available. The remainder must naturally find a market in the pig-iron producing States of Ohio, Pennsylvania, and Illinois. The great lakes provide a cheap and easy route for the greater part of the distance; consequently almost all the ore is taken in steamers from the nearest shipping port on the lake to Cleveland or some other receiving port on the south shore of Lake Erie, or to South Chicago, on Lake Michigan.

Ore-shipping docks and their accessories, as well as ore-carrying steamers, have been studied with special reference to the necessities of the case, and have been brought to a high state of efficiency. Saving of time and labour have been the objects mainly kept in view, and they have certainly been attained in a remarkable degree. Fig. 6 shows a cross-section of a wooden jetty, two of which, each 2000 feet long, constitute the ore docks at Duluth. Each jetty has throughout its entire length four pairs of rails. The distance between each pair is equal to the gauge (4 feet 8½ inches), so that waggons can also be taken between the pairs. Their contents are discharged through bottom doors into pockets or bins, as shown. Each of these will hold from 150 tons



THE DIPPER OF A STEAM SHOVEL

to 175 tons when full. The pockets are 12 feet apart from centre to centre, and the twelve to fourteen hatchways of the full-sized ore steamers are 24 feet apart; when loading, every alternate pocket is therefore opposite a hatchway. If these are all full, 2100 tons can be poured in at once. Then the steamer is moved forward 12 feet, and a similar quantity is discharged from the intermediate pockets. If the cargo is still incomplete the steamer can be warped ahead 450 feet and the operation repeated from another set. The total storage capacity of the ore docks is 100,000 tons.

If on the arrival of a ship the pockets are empty, ore is discharged through them from the waggons as fast as they arrive. In direct loading, the waggons, which are all 24 feet long to correspond with alternate pockets, are so placed that each is opposite a hatchway. If two full trains arrive together, there may be two waggons per hatchway discharging at the same time into the steamer. Only a portion of the vessels which load at the ore docks are built specially for rapid loading, and therefore the average

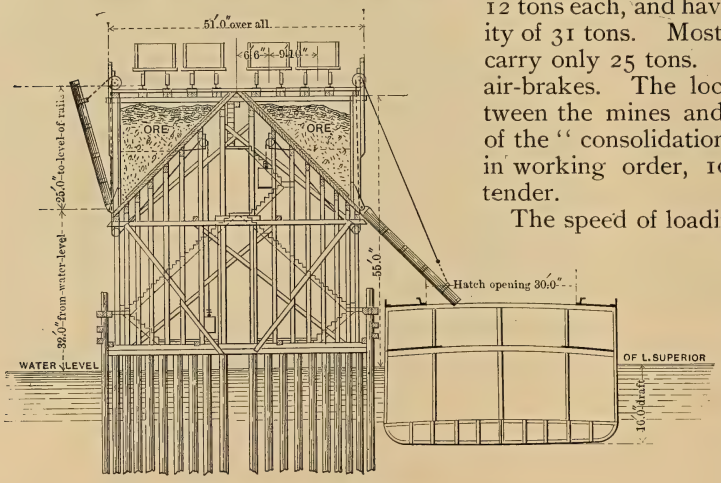


FIG. 6.—CROSS SECTION OF THE ORE DOCKS AT DULUTH

speed of through loading is much below the maximum. The current rate ranges from 1000 tons to 1600 tons per vessel per hour, the latter speed having been maintained for as long a period as 24 hours. The jetties are long enough to accommodate twenty vessels, in four rows of five each, moored end to end. The maximum draught for steamers to enable them to pass through the canals and locks is 16 feet 8 inches. On this

FIG. 7—PLAN OF DOUBLE-DIAMOND SORTING YARD

draught from 5000 tons to 6000 tons are often carried. To enable this to be done on an even keel the cargo must be carefully trimmed, an operation which is greatly facilitated by hinged bumper or baffle-plates, which are made to guide the stream of ore as it enters the hold. The older vessels are still trimmed by hand-labour. The inner surfaces of the pockets must slope at an angle of 45° with the horizontal. If the inclination is less the ore will stick when wet. The sides are composed of two thicknesses of 3-inch pine boards, lined with maple planks 4 inches thick. The spouts are of riveted steel plates, and are raised and lowered by winches at the rail-level. The ore waggons, of latest design, weigh 12 tons each, and have a carrying capacity of 31 tons. Most of them, however, carry only 25 tons. All are fitted with air-brakes. The locomotives used between the mines and the ore docks are of the "consolidation" type, weighing, in working order, 105 tons, with the tender.

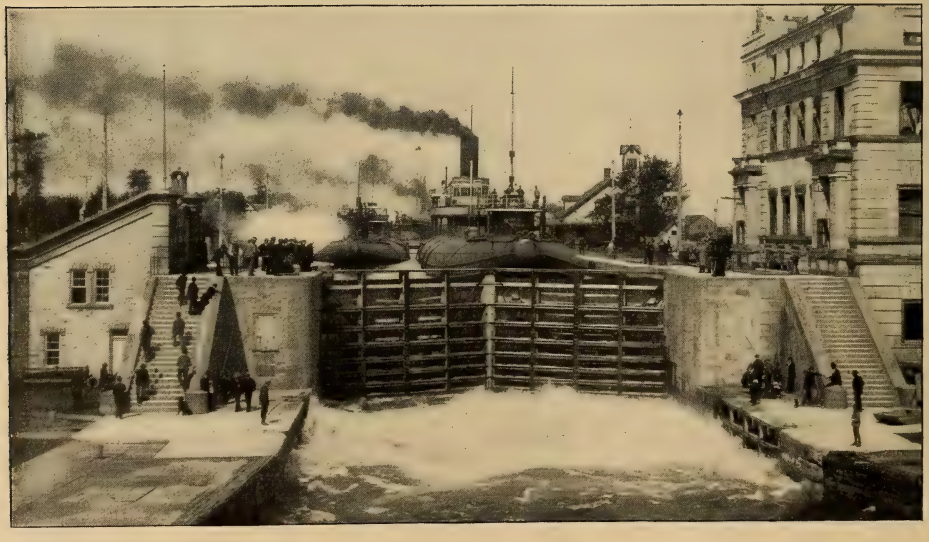
The speed of loading when the pockets are empty depends mainly on the rapidity with which the loaded waggons can be brought from the yard (or sorting siding) and the empties taken back. This is much facilitated by an arrangement such as that shown in Fig. 7, called a double diamond sorting yard. Each of the diagonal sidings is long enough to hold a train of forty-four waggons, those loaded being on one side, and the emp-

A VIEW OF THE OLIVER MINE

ties on the other. The Duluth ore docks contain in all six hundred and seventy-two bins, and employ one hundred and fifty men, who are paid at the rate of 6s. 3d. per day, and 6s. 8d. per night. There are also convenient offices and a large laboratory, with the requisite staff of officials. Not far from Duluth is the port of Two Harbours, which is the shipping place of the Minnesota Iron Company. Here are five jetties, each accommodating four steamers. In other respects the arrangements are similar to those already described, and the same may be said of all the other ore docks in the region. The magnificent deposits of rich and pure iron ore around Lake Superior have been developed and utilised only by extraordinary enterprise and ingenuity. This has been displayed at every step from the ore-bed to the finished steel now competing in the markets of the world. The faculty of adapting means to ends in an original way is nowhere better exemplified than in the modern ore-ship for lake transit. An observer is at first struck with its ugliness. The long, low vessel, with bridge, mas tand deck-houses piled up forward,

ORE VESSELS IN THE SAULT STE. MAIRE CANAL LOCKS

and boilers, chimney and engine aft, and no erections between them, is difficult to reconcile with previous ideas. But it is just this peculiar build which admits of the fourteen hatchways without obstruction, and the quick loading, unloading, and carrying on an even keel with only 16 feet 8 inches draught, of 6000 tons of ore. There are also other types, such as the "whale-back," which is not altogether unknown in Great Britain. Where these are employed, the custom is to have one fitted with engines towing two without engines. This is undoubtedly a cheap mode of conveyance, though slow. In

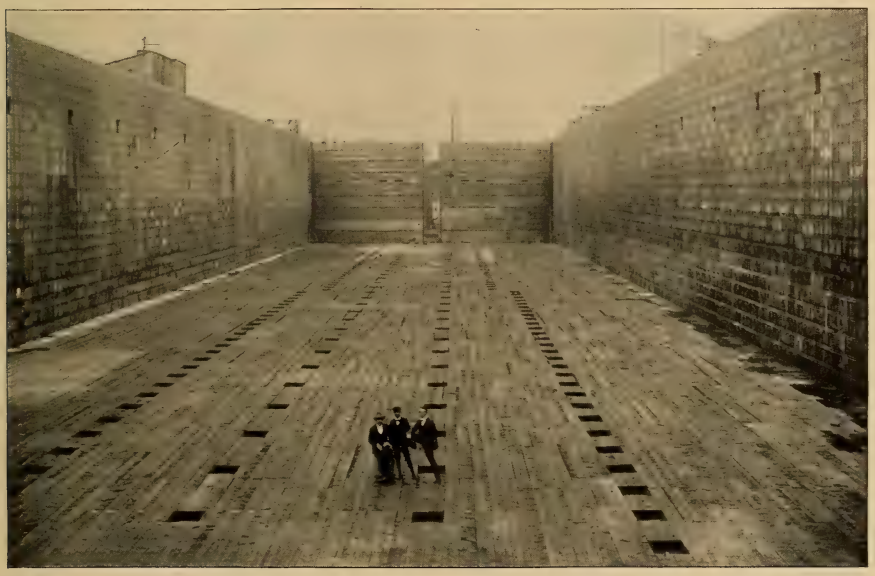


WHALE-BACKS IN ONE OF THE LOCKS

case of heavy weather, there is some danger that the towed vessels may have to be temporarily abandoned.

Except in the case of consignments from Menominee and Escanaba, all the ore vessels must pass through the "Sault Ste. Marie," or, as they are familiarly called, the "Soo" locks, between Lakes Superior and Huron. Of these there are three, viz., the old U. S. lock, the new U. S. lock, and the Canadian lock. The old U. S. lock was opened for traffic in 1881. It will pass vessels up to 600 feet long. At the upper end, and as far as the entrance to the lower gates, it is 80 feet wide. At the lower gates, however, it is only 60 feet wide. For filling from the higher level, there are two culverts 8 feet square in section, running the entire length of the lock, with openings upwards at frequent intervals. This system, which is common to the three locks, secures a rapid alteration of level with but little disturbances of the enclosed shipping. There are four pairs of gates in all; one ordinary pair at each end, one pair of guard-gates 80 feet wide beyond the upper end, and one pair 60 feet wide beyond the lower end. The average difference of level between Lake Superior at the high end, and Lake Huron at the low end, is about 27 feet. The gates are made of wood and are trussed. The depth on the sills is only 14 feet 6 inches, and is, therefore, insufficient for modern ore-ships when laden. The gates and subsidiary machinery are worked by hydraulic power obtained from accumulators sustained by turbine-driven pumps.

The new U. S. lock can pass ships 800 feet long by 100 feet wide. There are five sets of gates, *i. e.*, three pairs of ordinary, and two pair of guard-gates. The ordinary work of manipulating the gates and capstans is performed by accumulator pressure obtained from two 30 H. P. turbines. But there is also a steam pumping-plant of 750 H. P. for rapidly emptying the residual water in the lock in case of need.



THE NEW LOCK OF THE SAULT STE. MARIE CANAL

The Canadian lock is 900 feet long by 60 feet wide. It is said to be the largest in the world. About one-third of the traffic to and from Lake Superior passes through it. Vessels drawing 18 feet 3 inches have safely passed, but under ordinary conditions 17 feet draught should not be exceeded. The

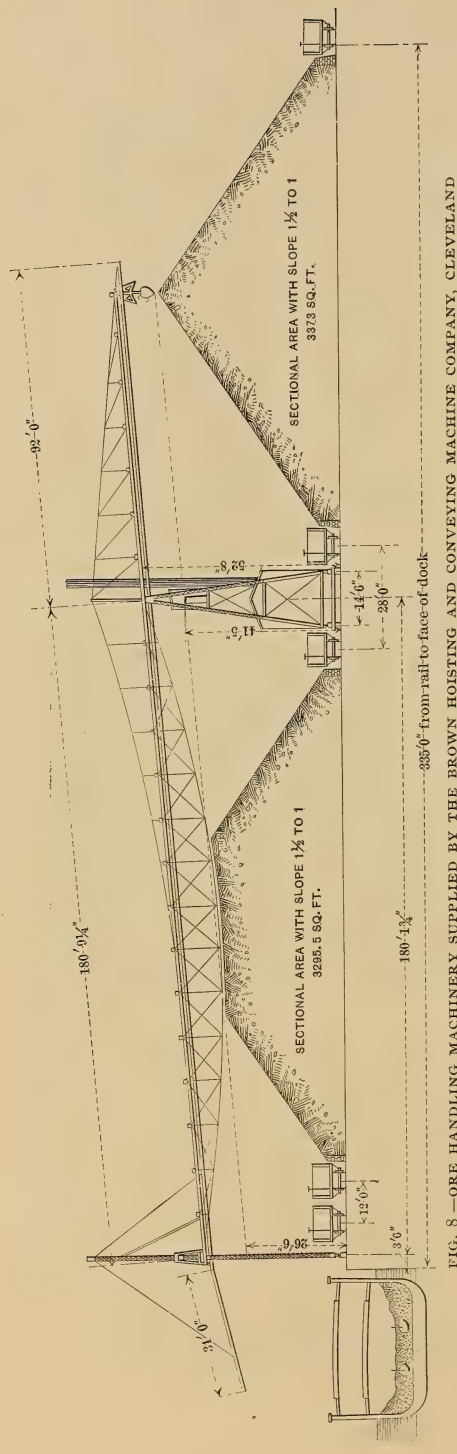


FIG. 8.—ORE HANDLING MACHINERY SUPPLIED BY THE BROWN HOISTING AND CONVEYING MACHINE COMPANY, CLEVELAND

machinery for opening and closing the lock-gates is operated by electricity, which is generated by power obtained from turbines. For Mr. Rockefeller's "Bessemer" fleet, a steamer 475 feet long, with a towed barge 450 feet long, have just been built. But none of the three locks will admit the pair without separation. The Canadian Soo lock was commenced in 1890 and completed in 1895. It cost about £700,000.

The pioneer lock between Lake Superior and the lower lakes is on the Canadian side. It was made in 1797 by the Hudson Bay Company. It is 39 feet 6 inches long by 7 feet 6 inches broad. It has a depth on the sill of 9 feet, and a lifting range of 9 feet. When in use the remaining 18 feet were surmounted by winding up on rollers the small craft of that day.

After passing through Lake Huron, the St. Clair canal is reached, and then Lake Erie, upon the southern shores of which the receiving ports of Lorain, Cleveland, Conneaut, and Erie are situated. Of these Cleveland is the most important. Here commences the railway leading to Youngstown and Pittsburgh, which are the principal consuming centres; and here are kept the immense stocks of ore which act as a fly-wheel to the trade. In the month of November, viz., at the end of the shipping season, there may be as much as 8,000,000 tons in stock, while in the month of April, viz., at the beginning of the shipping season, this may be reduced to 1,000,000 tons or less. On the arrival of the ore-ships at the receiving ports, the first necessity is facility for unloading their cargoes, and depositing them according to quality (which is already known), either in waggons for immediate despatch to the smelters, or on stock-piles for subsequent disposal or sale. These requirements are met in a perfect manner by machinery of a highly ingenious kind, with which the name of the Brown Hoisting and Conveying Machine Company, of Cleveland, Ohio, has hitherto been most prominently associated. Fig. 8 gives a side elevation of this machinery. It consists of a number

of so-called "bridges" arranged in groups of four, each bridge being carried on two pedestals or piers. The rear pedestals are on four wheels, and

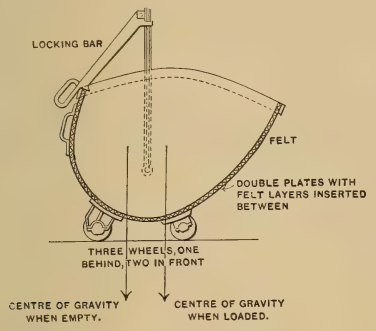

LOCKING BAR
FELT
DOUBLE PLATES WITH FELT LAYERS INSERTED BETWEEN
THREE WHEELS, ONE BEHIND, TWO IN FRONT
CENTRE OF GRAVITY WHEN EMPTY.
CENTRE OF GRAVITY WHEN LOADED.

FIG. 9.—DIAGRAM OF AN UNLOADING SKIP

those in front on two wheels. Between the back pedestals of one pair of bridges in each group is an engine-house containing four steam-winches and one boiler. To work these there are four winch-men and one boiler-man in every engine-house. Any bridge can be skewed 20 feet on either side of its centre line. It will be observed that the ore can with this apparatus be disposed of in several ways, viz.:—

(1) It can be taken out of the vessel and deposited in either the front or the rear stock-pile; (2) it can be taken out and loaded direct into waggons standing on any of the five lines of railway; (3) it can be taken from either of the stock-piles, and loaded direct into waggons standing on any of the five lines of railway; (4) it can be taken from the stock-piles, and loaded into a ship alongside the wharf.

The speed of unloading, when the conditions are favourable, that is to say, when twelve hatchways are being operated on with twelve bridges, and eight men are employed filling the skips in each hatchway, has reached 6000 tons in 8 hours, or 750 tons per hour, *i. e.*, nearly 8 tons per man per hour.

The unloading skip, Fig. 9, is a very important part of the apparatus. The most efficient, as regards size, is found to be one containing 15 cwts. of ore. Three of these are required to keep eight men and one bridge in continuous work. The skip is mounted on three small wheels, and is built up of two thicknesses of steel plates with felt between. This device is found to greatly increase the power of endurance. The cost of unloading ore and putting it into stock is stated to be between ¼d. and ½d. per ton.

The railway service from the lake receiving ports to the blast-furnaces at Youngstown, 75 miles, and Pittsburgh, 150 miles, is excellent. The lines are of standard gauge, and are laid with heavy rails. The locomotives average in weight at least 100 tons, with tender, in working order. The ore waggons carry not less than 30 tons, are on two bogies, and are fitted with air-brakes. The speed is about 16 miles per hour. The practice on the new Pittsburgh and Lake Erie line is, however, somewhat ahead of that on the older lines. It is

AN AUTOMATIC SKIP RELOADING FROM STOCK PILES

controlled by the Carnegie Company, and is used for ore and coal traffic only. The waggons hold 45 tons of ore, and weigh 15 tons each. They have central

STEAM SHOVELLING AT THE MOUNTAIN IRON MINE

ONE OF THE SHOVELS BUILT BY THE MARION STEAM SHOVEL COMPANY, MARION, O.

drop-hoppers, and are built entirely of steel. The engines are of the "consolidation," or eight-wheel coupled style, and weigh, with tender, when in working order, 127 tons. A train load is twenty-five to thirty loaded cars, carrying 1200 tons of ore, and weighing in all 1600 tons. The cost of conveying the ore under these favourable conditions is said not to exceed ⅛d. per ton-mile.

On arrival at the blast-furnace the ore-waggons can have their contents tipped, either upon stock-piles, for which abundant space is allowed, or direct into pockets from which a skip is filled, which is made to charge the furnace automatically. The machinery for unloading, carrying, and tipping upon the stock-piles is similar to that already described as in operation at the ore-receiving ports. But some explanation of the apparatus for automatically charging the blast-furnaces may be of interest here.

To equalise the burden, the spouted hopper at the furnace-top is made to rotate through a fraction of a revolution each time the skip empties its contents into it. When the bell is fully loaded, it is lowered, and is then raised again by pressure from the air-blast main. As the bell-chamber is completely sealed, no gases can escape when the charge is dropped. All being worked from below, there is no need for men above. The skips are loaded successively with ore, coke, and limestone, according to the proportions required in the charge.

The authors will conclude with a few remarks as to the influence of these abundant, excellent, and cheap ores, upon the supply of iron and steel to the markets of the world.

The following is approximately the cost price of one ton of Bessemer pig-iron at Pittsburgh, and at Middlesbrough, England, on January 1, 1899:—

PITTSBURGH	£	s.	d.
1.66 ton of ore at 12s. 8d	1	1	1
16 cwts. of coke at 7s	0	5	7
12 cwts. of limestone at 3s	0	1	9½
Labour	0	2	0
Repairs	0	1	0
Other items	0	1	0
Total	1	12	5½

MIDDLESBROUGH	£	s.	d.
1.93 ton of ore at 15s. 2d	1	9	7
20.5 cwts. of coke at 15s. 6d	0	15	10½
0 cwts. of limestone at 3s. 9d	0	1	8½
Labour	0	3	0
Repairs	0	1	0
Other items	0	1	0
Total	2	12	2

From these figures it appears that Bessemer pig-iron can be produced at Pittsburgh under present conditions for almost £1 per ton less than at Middlesbrough. This advantage is principally due to the Lake Superior ore and the Pennsylvania fuel supply. It will readily be seen that by the time the pig-iron has been converted into ingots, and further into finished steel, the advantage has been increased in proportion to the loss in conversion, and by reason of the lower cost of the fuel required in the later processes.

SELLING PRICES

	Pittsburgh, U. S. A.			Middlesbrough, England			Pittsburgh Prices Lower by—		
	£	s.	d.	£	s.	d.	£	s.	d.
Steel rails (heavy) per ton	4	2	9	4	12	6	0	9	9
Steel ship-plates per ton	5	10	9	6	15	0	1	4	3
Steel billets and blooms	3	2	6	4	5	0	1	2	6

These figures seem to show that the present low prices of American steel are justified, if only by the cheapness of the pig-iron from which it is made; and that the competition now felt in England and in neutral markets is likely to continue, and can only be met by lower costs on the part of English producers in all available directions.

Pittsburgh has been mentioned as the principal ore-smelting point, although there are others, notably Youngstown, in Ohio. Pittsburgh is 150 miles from Lake Erie. As only about 1.66 ton of Bessemer ore are required to make 1 ton of Bessemer pig-iron, and in the best practice only about 16 cwt. of coke, it is clearly better that the blast furnaces should be situated near the ore rather than near the fuel centre. This, however, involves other considerations of a somewhat complex character, such as the direction and distance of the centre

of consumption. Authorities in the United States are fairly agreed that the south shore Erie ports are the best smelting and distributing centres for pig-iron and steel, as well as the best receiving centres for the ore. The distance from Pittsburgh to Baltimore is about 300 miles, and the cost of railway transport and loading there of iron and steel goods in quantity would probably not exceed 4s. 2d. per ton. From Detroit to Liverpool,—by lake as far as Buffalo, by rail 400 miles to New York, and by steamer to Liverpool,— the through rate for charcoal pig-iron, in 2000-ton to 3000-ton contracts, but taken in lots to suit ocean steamers, is at present only 13s. per ton. Efforts are being made to improve the route from Lake Erie ports to New York by way of the Erie Canal, and it seems likely that this route, which avoids railways altogether, will increase greatly in importance.

As regards pig-iron, rails, and other steel goods, statistics showing recent imports from America to Great Britian have already been given. But naturally their competition will always be felt in distant and neutral markets more seriously than in those of the United Kingdom. Considerable consignments have already been made to Canada, South Africa, India, Japan, Mexico, South America and Australia, and they are likely to obtain a large share of what may in future be required in the development of Chinese railways and other undertakings, especially if, as seems probable, the Atlantic and Pacific oceans are united by a maritime canal.

The authors are inclined to the view that Lake Superior iron ores are likely to have a considerable and permanent effect in cheapening iron and steel and all goods made therefrom throughout the markets of the world; and that they will tend to encourage the production of such goods, and especially of ocean-going ships and engines at United States ports to a hitherto unprecedented extent.

SLUICE TOWER OF THE WATER POWER PLANT AT FOYERS, SCOTLAND

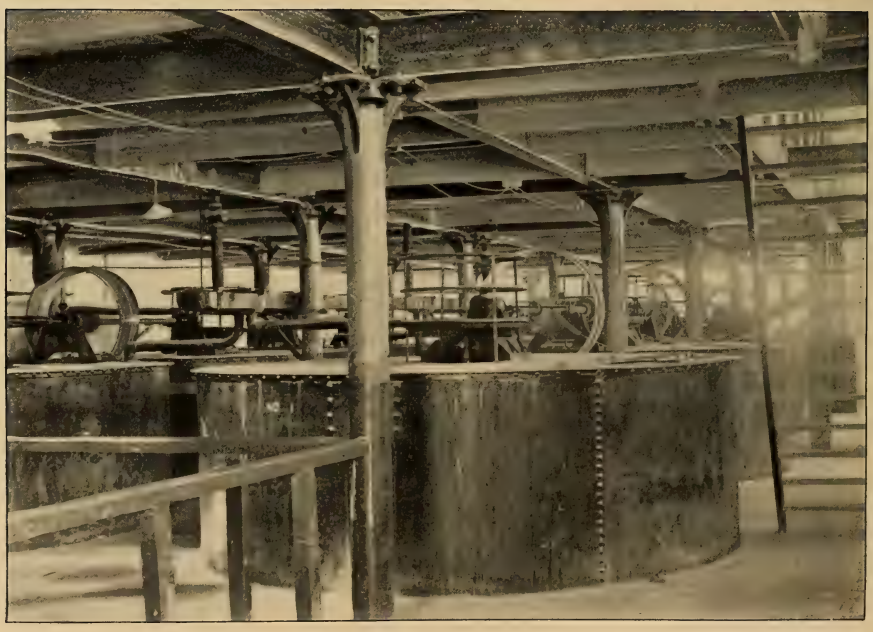
ALUMINIUM MANUFACTURE IN GREAT BRITAIN

By E. Ristori

WITH certain limitations, imposed by the chemical and physical peculiarities of the material, aluminium can be worked much like the other industrial metals handled at the present day. It is best melted in sand or in iron crucibles without the addition of any flux, at a temperature not greatly exceeding its melting point, 655 degrees C. = 1210 degrees F. On a larger scale, the operation can be carried out at a dark red heat on the bed of a reverberatory furnace lined with basic magnesia bricks of good quality. In casting, special precautions must be taken to allow for the great shrinkage during cooling. The moulds should have large risers and plenty of vents. They are preferably cooled from the bottom upwards to enable the gases to escape. Slabs for rolling must be cast in closed ingot moulds with a perfect machined internal surface, which is coated all over with graphite and water; the moulds must be very hot, and the castings cooled quickly in very cold water to make them soft.

Aluminium can be forged hot or cold, preferably at a temperature which causes a hard wooden stick to smoke when pressed against the metal. In comparison with other metals it ranks third in order for malleability and sixth for ductility; sheets have been hammered as thin as 1-40,000th inch, and wire can be drawn down to 1-250th inch diameter. No lubricant should be used for rolling; and the aluminium requires frequent annealing at a low red heat just visible in the dark. In turning, the edge of the tool soon becomes blunt, unless only small cuts are taken; the cutting speed should be high, and both tool and metal should be lubricated with

THE ALUMINA FACTORY AT LARNE

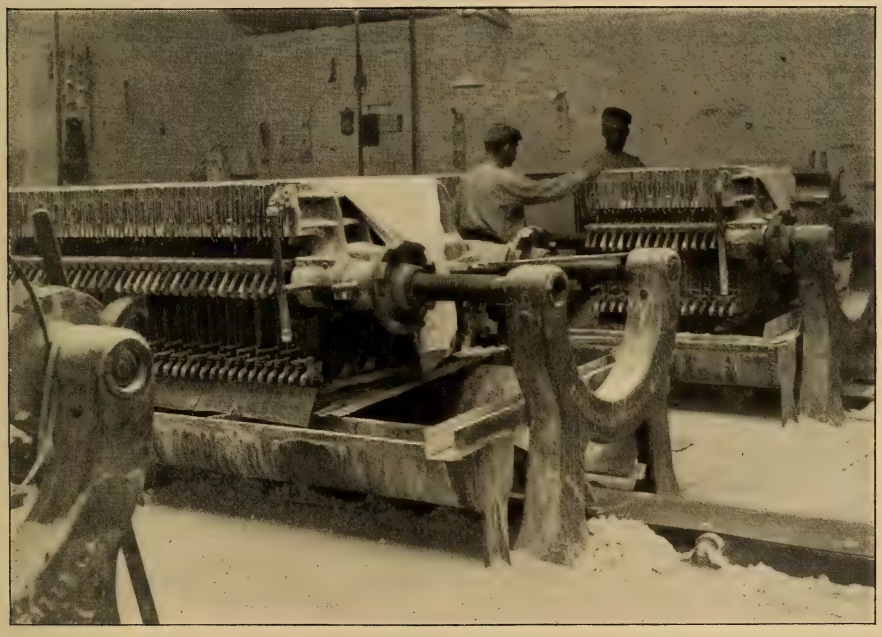


THE ALUMINA DEPOSITING CYLINDERS AT THE LARNE FACTORY

turpentine or petroleum. Filing is best done with single-cut files, because cross-cut files rapidly become choked. Spinning is easy on wooden or metal forms, the best lubricant being stearic acid dissolved in turpentine.

Aluminium can be stamped or pressed, hot or cold, either dry or with soap-water for heavy work, and with tallow for small goods. Frosting is effected by dipping the articles for a few seconds in a hot 10 per cent. solution of caustic soda containing about 2½ per cent. of common salt till the surface turns black, then brushing in cold water, and dipping in strong nitric acid until the metal becomes white again, and finally washing and drying in sawdust. This process is desirable before aluminium surfaces can be efficiently painted or enamelled. For polishing, a mixture of olive oil and rum is used, or emery and tallow, followed by rouge and turpentine. Burnishing is done with bloodstone or steel dipped in rum and oil, or in a solution of borax containing a little ammonia. To engrave aluminium, the plate must be coated with stearic acid and turpentine, or with rum and oil as before; if this be not done, the graver slips continually.

Among binary alloys especially it has been found that, as the proportion of the two ingredients becomes more and more equal, the products lose their valuable qualities, and that the industrial alloys may be broadly separated into two kinds, namely, "light" alloys, containing 90 to 99 per cent. of aluminium with 10 to 1 per cent. or even less of some other metal or metals; and "heavy" alloys containing 1 to 10 per cent. of aluminium with 99 to 90 per cent. of the other components. They can, therefore, be regarded either as pure aluminium strengthened by the addition of some other metal, or as one of the older metals improved physically and chemically by the addition of aluminium.



FILTER PRESSES AT THE LARNE FACTORY FOR HYDRATE OF ALUMINA

In its purest form aluminium is very soft, and not of great service in those arts in which much rigidity and strength are required. For this reason a metal containing only 98.5 to 98.8 per cent.

THE DYNAMO ROOM AT FOYERS

of aluminium, the impurities being silica and iron in almost equal proportions, is preferred to metal of 99.6 per cent. purity.

One casting alloy, having a specific gravity of 2.9, is largely used just now and is known as "No. 6." Its composition is still kept secret. It has been found to produce remarkably clean castings, which require very little machining to finish up; it takes a high polish, and so far has given complete satisfaction. Another alloy is "No. 4," which contains nothing but aluminium and a small proportion of copper; it is not one of the materials generally recommended, though it has some good qualities. There is a strong suspicion that, when aluminium is alloyed with copper, galvanic action is set up between the two, especially when the alloy is exposed to salt water; therefore, this is not recommended in any quantity for outside positions. The two alloys particularly recommended, as among the best yet made, are called "Wolframinium" and "Romanium." These are both ternary alloys, and, next to the aluminium, tungsten is the leading ingredient in each. In one of them copper is present to a small extent; in the other, nickel; and both have given astonishing results as regards strength and elongation. Samples of rolled sheet or rods made of these alloys have shown as much as 20 to 22 tons tensile strength per square inch with 5 to 10 per cent. elongation in 4 inches, which is remarkable when the low specific gravity of the material is taken into consideration.

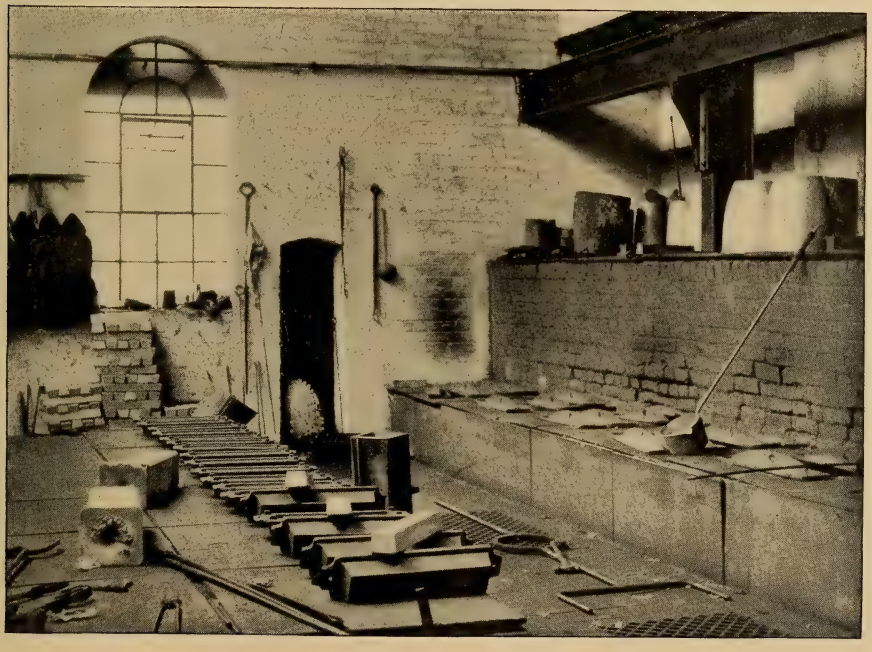
The above are all so-called "light" alloys, that is, alloys containing a preponderating percentage of aluminium with only a small quantity of other metal or metals.

There are many "heavy" alloys of aluminium, in addition to the well-known bronzes. Some of these have not yet reached the development to which their valuable qualities entitle them, and which they will ultimately attain when better appreciated by mechanical engineers. Aluminium bronzes are, undoubtedly, superior in strength to most of the copper-tin bronzes now in use; and they are especially suitable for marine engineering. Propellers of aluminium bronze have been successfully made for most of the 26 and 30-knot torpedo catchers; also a large number

	Breaking Load. Tons per square inch.			Elongation. Per cent. in 2 inches.		
Mark.	Max.	Min.	Mean.	Max.	Min.	Mean.
R3	36.6	30.8	34.0	35.00	15 50	23.30
R4	43.7	39.6	41.8	13.00	6.50	9.75

minimum, and mean breaking loads and elongations, agreeably with which R3 has a guaranteed tensile strength of 35 tons per square inch, with 25 per cent. elongation in 2 inches; and, when cast, R4 breaks at 40 tons per square inch, with 10 to 12 per cent. elongation, also in 2 inches. These have the advantage of being considerably cheaper than other bronzes, and are easily employed for any foundry work without special appliances or tools.

The principal uses of aluminium are too many to be enumerated. The properties of the metal are so akin to those of copper and brass that, broadly speak-



THE CASTING SHOP AT MILTON

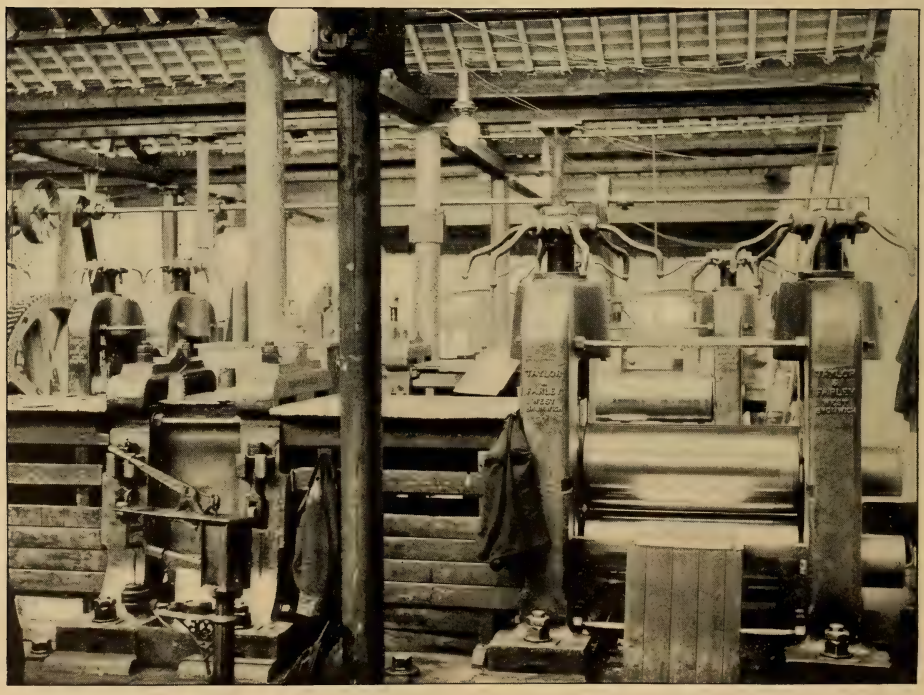
for the French Government. The two classes of bronze most frequently employed are marked R3 and R4; the difference between them is simply in the proportion of aluminium they contain. The following tests show their maximum,

ing, aluminium or one of its light alloys should to a large extent replace both copper and tin and also nickel or German silver. Such a change would be followed by various advantages to all concerned. Not only would there be a

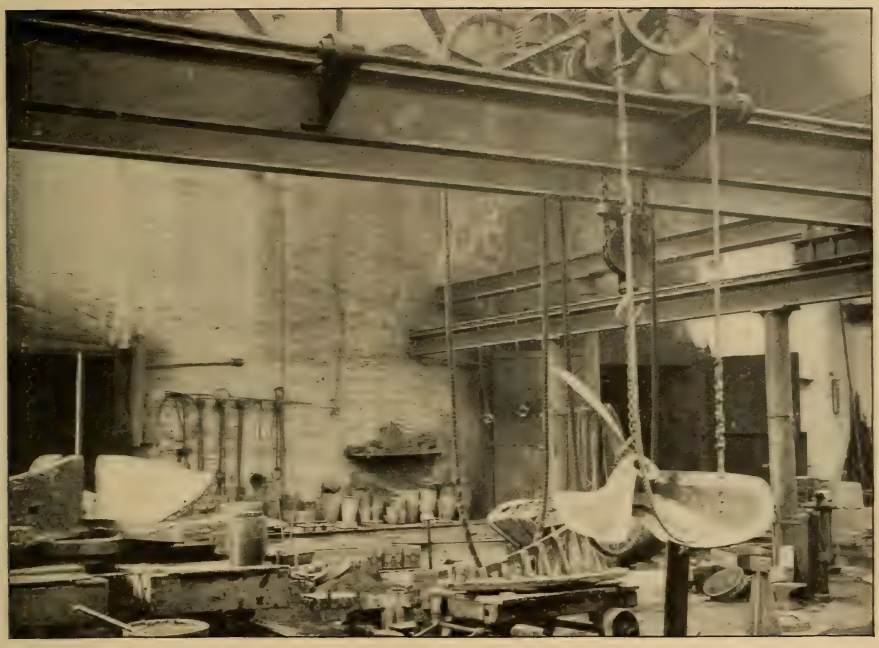
considerable reduction in the weight of the articles, but they would not tarnish or turn black on exposure to air. The cost should be the same, if not actually lower, inasmuch as, bulk for bulk, aluminium is already cheaper than copper or tin; and its price will continue to fall as the demand increases. One field, however, remains which copper is bound to maintain as its own, namely, the construction of insulated electrical conductors. Experiments have already been made on a large scale with bare conductors of aluminium for telephones, and the British Aluminium Company are using it in this manner at their Foyers works with perfectly satisfactory results, its conductivity, weight for weight, being double that of copper. But when the mains have to be insulated, copper is absolutely unapproachable, on account of its greater conductivity, volume for volume, which is 165 per cent. of that of aluminium.

Besides the advantages set forth above, aluminium is not poisonous, and is pre-eminently adapted for the manufacture of cooking utensils. On the other hand, tin ware is not particularly cheap in the long run, for it is constantly wearing out; cast iron is heavy and brittle; and copper requires to be frequently re-tinned in order to avoid all danger to health. Inasmuch as an aluminium saucepan costs no more in the first instance than a copper one, weighs much less, is perfectly innocuous, and does not periodically need a fresh inside, it is not surprising that the employment of aluminium in kitchens and canteens is spreading rapidly.

A steady demand for aluminium is springing up in various kinds of printing processes, as well as in lithography. The metal appears to answer admirably for the construction of rollers used in calico printing; and when its surface is properly prepared, it is also capable of replacing the ordinary lithographic stone. It can easily be imagined that, instead of having cumbrous and heavy stones, which can be printed only on



THE ROLLING MILLS AT MILTON



A VIEW OF THE ALUMINIUM FOUNDRY AT THE MILTON WORKS, SHOWING ALUMINIUM BRONZE PROPELLERS

special slow-running "litho" machines, it is far better and cheaper to use thin sheets of a metal which can be bent into a circular form and printed on rotary presses.

Bicycles, electric-light fittings, chains, bridles, stirrups, surgical instruments, sextants, and other scientific apparatus, keys, cigar cases, pen and pencil holders, toilet articles, plates and dishes, spoons, forks, frames, name-plates, door furniture, hat and coat pegs, boot-trees, fire-engine fittings, business and visiting cards, and photographic cameras are a few of the things that are being daily made in aluminium by various firms, and all these articles should be sold at the same price as if they were composed of brass.

There are other instances where aluminium should economically replace commoner metals than copper or brass. Wherever a great deal of dead weight has to be continually moved about, the cost of motive power, for which there is apparently no return, is serious; and if this unremunerative weight can be reduced to one-third of its present amount, in the course of a year or two the saving in power will more than compensate for the greater initial outlay. Thus frames for cabs and motor-cars have already been made in aluminium; and though in Great Britain experiments have not yet been tried in this direction, aluminium railway-carriage frames are under review in France. Especially for motor-cars should there be a large field here for aluminium. A further demand for the metal will be brought about by its introduction into the military services. All parts of the soldier's equipment have practically been made already in aluminium, such as mess tins, water bottles, buttons, helmets, parts of rifles, cartridge cases, fittings for guns, tents, horseshoes, portable bridges, etc. Nothing much has yet been done in Great Britain in this direction; but it is well known that continental armies, notably the German army, are employing aluminium on a large scale.

One of the largest uses to which aluminium has been applied is in metallurgy.

THE FURNACE DEPARTMENT AT GREENOCK FOR BAKING THE ELECTROLYTIC CARBONS USED AT FOYERS

It is common knowledge among steel makers that ingots often turn out spongy at the top, and when particularly good ingots are required, the faulty portion is cut off and melted over again. By the addition of a very small proportion of aluminium to iron, steel, or brass, either in the mould or in the ladle, the founder can be quite certain that the ingots will be solid all through. When used in this way, aluminium has the peculiar virtue of instantly liberating all the gases contained in the metal, and of keeping it fluid for a longer period, so that by the time the casting solidifies, the gases have had an opportunity to escape. In almost all steel works, and in all the principal foundries, aluminium is now being employed, and reports from some of these state that the result is a reduction in the wasters by 80 or 90 per cent. In this case aluminium does not actually replace any other metal, but by its own special qualities is useful as a means of improving physically and chemically some of its older rivals and friends.

The use of aluminium in shipbuilding is growing rapidly, on account of the almost inestimable advantage of its great saving in weight. Four or five years ago a small canoe was made on the Thames of two sheets of aluminium, stamped and riveted together. In 1892 Messrs. Escher, Wyss & Co., of Zurich, constructed a small launch entirely of aluminium, driven by a naphtha motor, and in the following year they built for Mr. Nobel another larger vessel which has been in use ever since, and is now on one of the Swedish lakes. During 1894 and 1895 the author had on the Thames, between Windsor and Maidenhead, a similar vessel, which is now at work at Foyers. A much more ambitious attempt was made by Messrs. Yarrow in 1894. By request of the French Government they built of aluminium the whole of a second-class torpedo-boat, 60 feet long by 9 feet 3 inches beam. This boat weighed in full working order, but exclusive of armament, only 9½ tons, and attained, during a run of two hours, carrying a load of 3 tons and with engines indicating about 300 H. P., a mean speed of 20½ knots,—an advance of 3½ knots over all previous records.

Several yachts were also constructed at the same time, but they do not seem

to have been a real and permanent success, owing probably to the adoption of an unsuitable alloy. As pure aluminium was not strong enough alone, it was thought better to use an alloy containing about 6 per cent. of copper in the construction of some of these boats. This alloy possesses a tensile strength of 14 tons per square inch; but, as already stated, this material is absolutely untrustworthy in sea water, owing to the rapid corrosive action set up between its two ingredients. Moreover, although nobody would dream of employing any other metal than copper for plating seagoing vessels unless it were afterwards painted, aluminium has always been used bare, which the author considers a mistake. If the aluminium had been protected from direct contact with the water, it would have lasted much better.

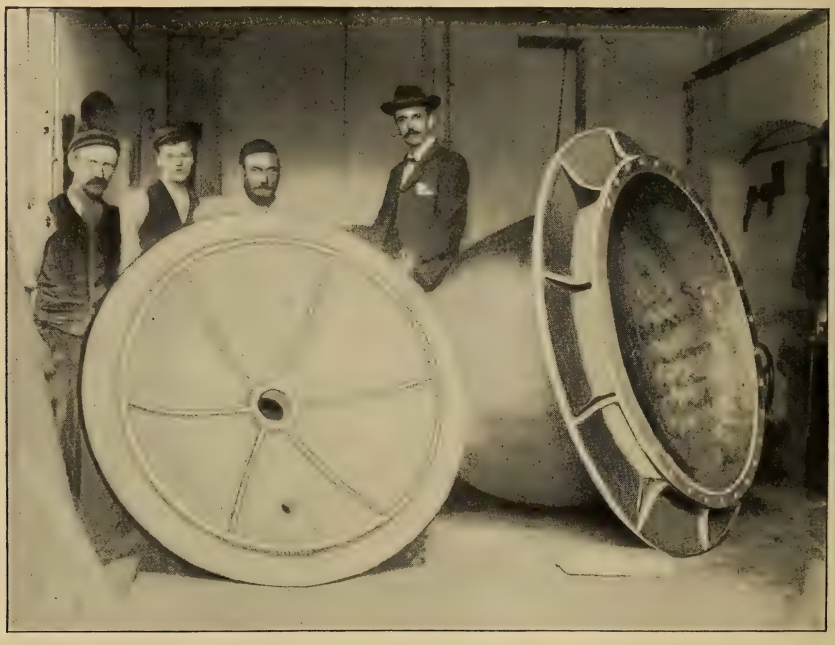
Unfortunately this comparative failure has materially discouraged the adoption of aluminium in shipbuilding; and although it is now well recognised that the pure metal, and several of its alloys which do not contain copper, stand the action of salt water better than iron or steel, some time is likely to elapse before these premature tests are forgotten. Eventually, however, when further experiments have been carried out, there is no reason why a suitable alloy should not be adopted which, when properly used and protected from direct contact with sea water, would resist corrosion as effectually as the majority of materials now employed in shipbuilding. These remarks refer only to the keel and other parts of the vessel below water, and chiefly to such craft as are to navigate the open seas.

For all internal work aluminium is perfectly safe, and it is specially suitable for adoption in the navy where the presence of wood and other inflammable material should be discouraged as much as possible, lest it lead to fires during action. In all boats sailing on fresh or inland waters the corrosion is less; and when portability is desired, as in the case of expeditions to little known parts of the world, even if the aluminium do suffer corrosion, this is of trifling moment in comparison with the advantage of smaller weight to be transported.

THE ENTRANCE END OF ONE OF THE BAKING FURNACES

For instance, Messrs. David White, of Glasgow, have recently constructed an 18-foot boat for a party going to the Klondike district, weighing only 1¾ cwt., which is wholly composed of aluminium, even to the rivets, nails, bolts, and nuts. It is made in sections which pack into one another, and the whole can be put into a box. Messrs. Forrest & Son, of Wivenhoe, also furnished a flotilla of two launches and a barge for Major Gibbons' trans-African expedition. The vessels were built in sections on the sentation by the author to the Institution of Mechanical Engineers.

The Milton works were the first ones erected in the United Kingdom for the production of aluminium by electrical agency. They were erected by the Cowles Syndicate for the purpose of turning out aluminium and aluminium-bronze by the well-known Cowles process; but before the British Aluminium Company took them over they had already stopped making aluminium, having been previously driven out of the



A LARGE ALUMINIUM CASTING FOR CHEMICAL WORK. TOTAL WEIGHT, 14 CWT.

Hodgetts principle, each piece measuring about 6 feet 6 inches by 3 feet 9 inches and weighing less than 120 pounds, so that two natives can easily carry one between them by means of oars on their shoulders.

In connection with this brief résumé of the properties and uses of aluminium, it will be interesting to refer more particularly to the works at Milton, in Staffordshire, of the British Aluminium Company. The following account of these, as well as most of the data already given, were originally prepared for presentation by the author to the Institution of Mechanical Engineers.

The Milton works were the first ones erected in the United Kingdom for the production of aluminium by electrical agency. They were erected by the Cowles Syndicate for the purpose of turning out aluminium and aluminium-bronze by the well-known Cowles process; but before the British Aluminium Company took them over they had already stopped making aluminium, having been previously driven out of the field by the competition of the electrolytic methods, which were greatly assisted by the employment of cheap water power. It was found useful, however, to convert this factory into a rolling mill and foundry, with the idea not only of refining the ingots made at the company's works at Foyers, in Scotland, but also of working them up into sheets, rods and large or small castings, more convenient for the different trades that use aluminium.

The Foyers works draw their supply of pure alumina (oxide of aluminium)

AN ALUMINIUM TORPEDO BOAT BUILT FOR THE FRENCH GOVERNMENT BY MESSRS. YARROW & CO., LTD., LONDON. LENGTH, 60 FEET. BEAM, 9 FEET 3 INCHES

from the company's factory at Larne, where the alumina is prepared from bauxite. The finished product is a very finely divided powder, and in order to ship it safely to Foyers it has been found advisable to pack the alumina in hermetically sealed steel drums. On arrival in Scotland, the oxide is reduced by the Héroult process, and the metal is run out of the electrolytic baths into ingot moulds. In this form the aluminium is quite pure enough for certain purposes, such as foundry work and steel making, and much of it is, therefore, sold without further treatment. But as small quantities of the cryolite, —a double fluoride of aluminium and sodium containing 13 per cent. of aluminium,—which is used as a solvent during the electrolysis, occasionally become mixed with the metal as it comes out of the furnace, the aluminium at this stage is scarcely suitable for the production of tubes, rods, etc. The original crude ingots are, therefore, sent to the Milton Works, where they are re-melted and refined until the metal attains a purity of 99.6 per cent.

The casting shop at Milton, erected in 1895, contains a series of eleven furnaces for 500-pound pots, connected by a large flue to the main chimney, 125 feet high, which gives a good draught for melting large quantities of bronze in a short time. This shop can deal with about four tons of aluminium per day, in the shape of ordinary commercial notched bar, half-round stick for steel-makers, slabs for rolling, tube billets for drawing, wire billets, both round and shaped for various purposes. When casting the metal, it is sometimes necessary to add a little cryolite or some similar flux for assisting in the liberation of the impurities, which then rise to the surface as scum. These refining furnaces are fired with soft coke, because aluminium does not require such a high temperature as is necessary for bronze. The scum taken from the top of the pots is again remelted very slowly, in order to recover all the aluminium; it then forms a whitish powder, containing practically nothing but the cryolite and some carbon, and being quite suitable for use in the Héroult reducing cell, is sent back to Foyers for further employment. An overhead traveling crane is used for lifting the ingot moulds and pots. Experiments have been made in casting slabs and billets with a side runner, which seems to offer certain advantages.

The principal building, which was originally intended by the Cowles Syn-

dicate to be an engine and dynamo house with outside boilers, is 200 feet long by 65 feet wide and 20 feet high under the principals. A portion of this is now used as a foundry, and contains two large core ovens, each 16 feet by 23 feet, having a door 14 feet by 10 feet high, fired with coke fires under the floor; a cupola; two series of crucible furnaces to hold 500-pound pots, and two travelling cranes, sufficient to handle weights up to fifteen tons, which, so far, have been sufficient for all the foundry work up to bronze castings of five tons weight, and aluminium castings of two tons. A considerable extension of the plant is contemplated.

In making bronze castings, the metal is not poured straight into the mould in the usual way of casting iron, but into a runner box, or, for a large casting, into a number of runner boxes, having holes in the bottom corresponding with the gates of the casting. During the time the metal is being poured into the runner box these holes are filled with iron plugs until all the metal is in the runner box; the plugs are then taken from the holes, so that the metal runs into the gates of the casting from the bottom of the runner box, and leaves the scum behind in the box, or in the top of the gates. In making castings of aluminium, it is not sufficient to use runners of the same size as those usually employed in making brass and iron castings. As the shrinkage of aluminium is about three times the shrinkage of ordinary gun-metal, a considerable amount of trouble is experienced if the runners and risers are not large enough to allow the casting to continue to be fed during its shrinking.

The rolling shop measures 130 feet by 60 feet, and is covered with a weaving-shed roof having a north light. At present it contains two pairs of rolls 18 inches in diameter by 42 inches in width; one pair 18 inches in diameter by 48 inches in width; one pair 18 inches in diameter by 20 inches in width; one pair 14 inches in diameter by 20 inches in width; one pair 14 inches in diameter by 30 inches in width, and a new pair of friction rolls 22 inches in diameter and 60 inches wide. All are driven by gearing from a horizontal, tandem, compound-condensing engine. The driving gear consists of helical tooth wheels, 12 inches wide and from 6 feet to 9 feet in diameter, driving the rolls at about 10 revolutions per minute.

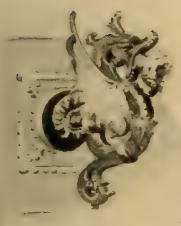
The rest of the plant required in a rolling mill is also contained in this building. It includes two guillotine shearing machines for ½-inch plates, 8½ feet wide; a crocodile machine for plates up to 1 inch thick; two circular cutters, one for the manufacture of disc blanks 9 inches to 24 inches in diameter up to 14 S. W. G., or 0.085 inch thick, the second, up to 4 feet in diameter and ⅜ inch thick, which are sold for stamping purposes; a steam hammer, for closing the grain and for strengthening alloys before they are rolled into sheets, is in an adjacent building. A press is also being prepared for punching discs up to 12 inches in diameter. Two annealing furnaces, or muffles, are also provided, 5 feet by 12 feet, and 7½ by 14 feet; these are a most important item in the plant for either rolling or hammering metal. Slabs 24 inches wide by 1¼ inches thick are broken down hot, after being heated in the muffle; they are afterwards again heated when necessary between the successive passes to reduce them from 1¼ inches thick to ¼ inch. Most of the rolling itself is done cold, and in some cases, especially when very pure aluminium is used, even the breaking down can be done cold. Connected with the rolling mill is a pickling shop, containing tanks 12 feet by 3 feet, charged with caustic soda, water, nitric acid, sulphuric acid, etc. The pickling process has to be carried out whenever a good polish is required on the finished sheets, while it is also equally adapted when a mat surface is desired.

The fitting shop is subdivided into several buildings, and is provided with a quantity of ordinary lathes, circular and band saws, a nicking machine, shaping machine, and a number of small presses for cutting blanks out of sheet metal. In another building next to the rolling mill there is a cold saw to cut metal 20 inches thick, especially used

for cutting heads off aluminium-bronze castings which cannot be handled or cut up in any other way. If the bronze is made hot, it can be forged into any shape. Most of it has a tensile breaking strength of 30 to 35 tons per square inch, and it is useless trying to handle the heads in any other way than by sawing. The Milton factory contains also a 30-ton Wicksteed testing machine, in which the different bronzes and light aluminium alloys are constantly being tested. There is also a chemical laboratory, in which the sample tappings from the furnaces at Foyers are analysed and records preserved, so that the purity of any particular delivery can be ascertained.

STORAGE BATTERIES VERSUS ELECTRIC ISOLATED PLANTS

By Alton D. Adams



THE present position of storage batteries in electrical supply is that of an adjunct to generating equipment. In both central stations and isolated electric plants they tend to maintain a constant pressure under varying demands, and supply all of the energy at minimum and a large per cent. at maximum loads. As the storage battery must give out less electric energy than is put into it, the ability to displace isolated generating equipment seems at first entirely lacking. Facts are not wanting, however, to show that batteries on the consumer's premises may be so used in connection with central station supply as to frequently effect a saving over private generating plants.

Public and private plants each have their peculiar advantages for the economic production of electric energy. Central stations burn less coal per kilowatt-hour of output, but isolated plants are frequently able to use exhaust steam for heating purposes during about one-half the year, and thus gain as heat what they cannot get as light. The public plant, on the other hand, is able to distribute only about 10 to 14 per cent. of the available fuel energy. The proportionate labour charge is less for the public station, but interest and depreciation items are smaller in the isolated plant, and the use of exhaust steam heat and the low interest and depreciation in private plants usually more than offset the smaller fuel and labour items of the public supply.

It is generally cheaper for large consumers to operate their own electric plants than to buy energy from the central station. These facts are illustrated by the increasing number of isolated equipments that dot the area of public supply in large cities where central station service is worked out on the most economical basis. The charge for electric energy from the public supply is a variable quantity, changing with the quality, quantity and distribution as to time of the service required. In New York City the average charge per kilowatt-hour, according to the last report of the Edison Electric Illuminating Company, was 10.6 cents during the past year. Electric energy for power purposes alone can be had in New York City, as in many other American cities, at a rate of 4.5 cents per kilowatt-hour, but for electric lighting the charge is higher and depends on the conditions of each case.

In isolated plants the cost of electric

energy is a more complex problem than in central stations, since it is not easy in many cases to determine just how much of the fuel and labour costs should be charged to the electric service and how much to heating and power requirements. Conditions differ, but the actual cost of production for electric energy in many private plants in the United States has been found to be about 4.5 cents per kilowatt-hour. In some instances where the labour charge would be the same with or without the electric equipment and where exhaust steam can be used to the best advantage, the cost of electric energy produced by isolated plants may fall as low as 2 or 3 cents per kilowatt-hour, but this is exceptional. As the average charge for electric energy from the public supply is about twice its usual cost in isolated plants, it is evident that means must be found for a very large reduction in central station rates before they will offer a saving over private equipments

The cost of service from public plants is largely determined by the conditions of supply. The demand for light is such with most large consumers that the heaviest load and a large per cent. of the total load are carried during hardly more than four hours per day. When incandescent lamps are operating at or near their normal candle-power and pressure, a small drop in the pressure produces a great decrease in the light produced. For example, a lamp for 110 volts will hardly give more than one-half its rated light on a 105-volt pressure. An equipment of generators, engines and boilers, or of these combined with storage batteries to a capacity far in excess of the average load, is made necessary by the concentration of the major output on a few hours of each day, and this results in a large interest and depreciation charge.

As the distribution system between the station and consumers must be proportioned for the maximum, rather than the average, load, the necessary investment again involves interest and depreciation items that are large compared with the value of energy delivered to consumers. As matters now stand, the average user of incandescent lamps on central station supply must pay not only for the proportionate costs of operation during the time his light is required, but also an additional sum toward interest, labour and depreciation on plant when his lamps are not in use. The necessity for exact regulation of pressure at the lamps which is peculiar to incandescent service, materially increases the cost of distribution systems and adds, again, to the interest and depreciation charges.

Electric power rates, as above noted, are usually much lower than those for service to incandescent lamps. The reasons for this difference are largely the fact that the use of electric power is generally distributed over about ten hours per day, thus giving central stations considerable loads at times that would otherwise have only small demands, and further, because the requirement for constant pressure is by no means as exacting with electric motors as with incandescent lamps.

In order to materially decrease the consumer's charge on central station supply, therefore, the demand for energy must be more uniformly distributed over the day, so as to cut down the investment in station and distribution equipment for a given output per twenty-four hours. A reduction of the total energy output at a station to a nearly uniform load during a large part of each day will further reduce the cost of the distribution system by making the problem of pressure regulation at consumers' premises easier of solution. The comparatively low rates for electric energy delivered to motors illustrate, to some extent, what may be expected for long and uniform loads that do not require pressure regulation so exact as is the case with incandescent lamps. Electric motor loads are fixed as to time and do not continue as many hours per day as would be of the highest advantage to central station operation, and they also overlap during several hours the time of greatest requirement for incandescent lamps, thus contributing to the maximum loads.

Consumers of electric energy who will take their supply during any part of the

twenty-four hours best suited to the central station are, therefore, in a better position to secure low rates than are the users of electric motors.

A suitable equipment of storage batteries puts the user of electric light in this advantageous position. With a battery large enough for the daily consumption and the maximum load, the central station supply may be taken during the midday hours and after ten o'clock at night, when demands on the central station are smallest and most of the generating machinery is normally out of use. Under these conditions energy can be supplied by electric stations, with profit to themselves, at a lower rate than is now made for any class of service, since but slight additional expense will be incurred beyond the cost of the extra fuel burned. The opportunities which storage battery equipments thus offer are particularly open to those who would otherwise naturally install isolated plants.

Batteries require but a small fraction of the attention necessary for generating equipment; but they must have a little, and, moreover, their cost at the start is considerable. For these reasons the great majority of small and moderate consumers will prefer to purchase their supply of electric energy direct from the public plant, thus saving the care and expense of intervening devices and supervision. The unequal distribution of central station loads, as to time, that is now so favourable to those whose supply can be taken during periods of smallest demand, is not, therefore, likely to disappear, though storage battery plants tend to relieve the condition.

A large consumer of electric energy may install a storage battery, if in his case it is shown to be more economical in operation than an isolated plant, with the certainty that the ability to receive the daily supply at times best suited to the central station will remain a permanent advantage. Whether the storage battery will be more economical than the isolated generating equipment in any particular case depends upon special conditions. Where the exhaust steam cannot be used for heating purposes during four to six months of the year, the chances, in general, are favourable to batteries, unless the power necessary for electric lamps is only a small part of that generated in the plant. The labour must, in any event, be a large item in isolated plants for office and mercantile buildings, and the saving in this direction will often warrant the use of batteries even in cases where exhaust steam is desirable for heat during a part of the year.

Though steam for heating is an important item in the operating expense of a large building it should be held in mind, first, that heat is required during not more than six months of the year, and, second, that the quantity and quality of labour necessary to care for a steam-heating boiler during one-half of the year is quite different from that needed to run a high-pressure power boiler, engines and electric generators during the entire year. If the battery equipment is adopted, all steam power should be abandoned and electric motors substituted.

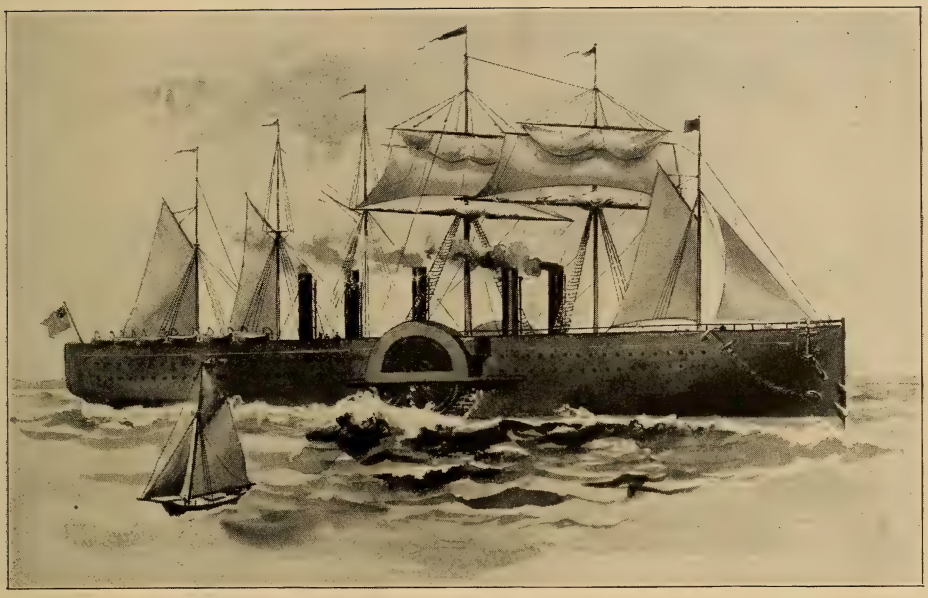
The labour charge to operate heating boilers, batteries, electric motors and the general machinery of a modern building will certainly be less than that to operate power boilers, engines, steam pumps, electric generators and the same general machinery, but how much less, must be decided on the facts of each case.

A properly erected storage battery requires but little attention, and that of a kind involving care rather than a high degree of skill. The efficiency of the storage battery is high under normal conditions; with fair care for stationary work it should not fall below 85 per cent., and may be kept near 90. For complete generating equipment in an isolated plant, covering boilers, pumps, piping, engines, foundations and electric generators, the cost in the United States may be taken at about one hundred dollars per kilowatt capacity of output, all in position to operate.

Storage batteries have a greater proportional first cost which will vary from two hundred to three hundred dollars per kilowatt output at a moderate rate

of discharge, which latter is necessary to insure low battery depreciation and high efficiency of operation. First cost in case of the battery, as with other power transforming devices, is of small moment compared with efficiency of operation and its cost relative to that of other methods. With electric energy distributed to the batteries at less than 4.5 cents per kilowatt-hour,—the rate for motor service,—there is no doubt of the superior economy of batteries over generating equipment in many cases. Further facts in favour of the battery are the small amount of space required, entire absence of jar, noise and heat, and the increased certainty of the supply.

If the tendency in many of the largest and best public supply systems may be taken as a guide, the storage battery is well suited to displace small generating plants. One of the most marked changes in the supply of large and heavily loaded areas of electric service at the present time is, indeed, the abandonment of lesser steam plants and the substitution of batteries in their places, while the generation of electric energy is concentrated at a few steam power stations of enormous capacity.



THE "GREAT EASTERN," 1859.—LENGTH 680 FEET; DISPLACEMENT 24,000 TONS

THE INCREASING SIZE OF STEAMSHIPS

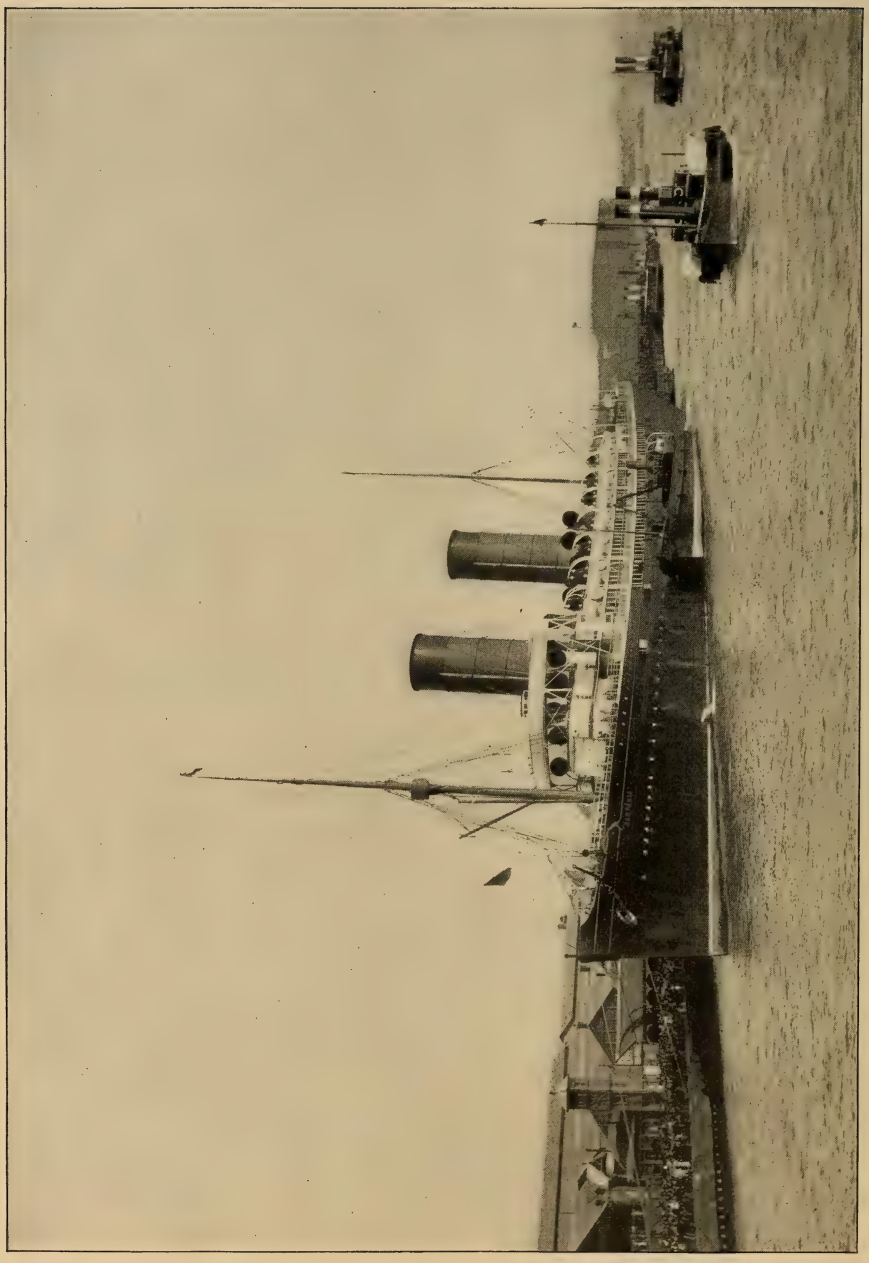
By Herbert C. Sadler, B. Sc., M. Inst. N. A.

WITHIN the last ten years there has been a steady rise in the size of steamships, and at the present day there is a general tendency towards a still further increase. Generally speaking, the length of both passenger and cargo vessels has increased at a greater rate than the remaining dimensions.

Two factors govern the actual size of a vessel,—(*a*) dimensions, (*b*) bulk, compared with the circumscribing parallelopiped. The problem to be solved by the naval architect resolves itself into the following form:—A floating structure is to be made which will carry, besides its own weight, a certain weight of cargo at a given draught; will move at a certain rate of speed and at the same time carry sufficient fuel to enable her to reach a certain point; will carry this total burden with safety, and, more especially in passenger vessels, comfort; and will possess sufficient strength to withstand any stresses to which it is liable. In short, a vessel must have a certain displacement, power, coal supply, stability, and strength.

In order to show the general effects of increase in size, it will be convenient to divide vessels into two classes,—passenger and cargo ships. In the first division speed is of primary importance, and in the second, weight-carrying. It is evident that increase in size, in the first division must take place in dimensions rather than bulk on account of the high speed, and, therefore, large power required; but in the second division both dimensions and bulk may be increased, depending upon the nature of the conditions to be fulfilled.

Generally speaking, the carrying power of both cargo and passenger ves-



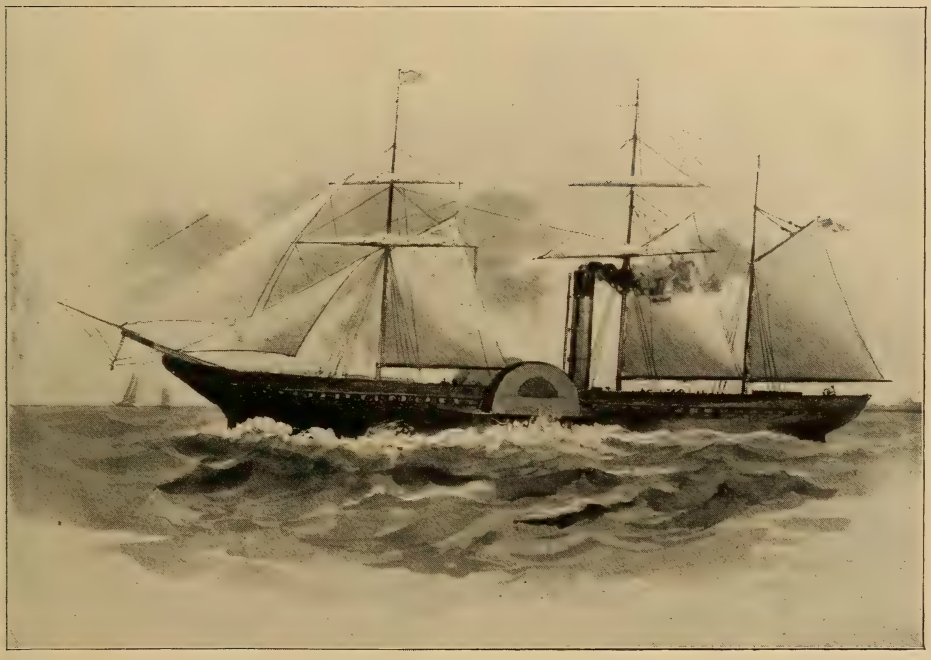
THE TWIN-SCREW CUNARD LINER "CAMPANIA." LENGTH, 622 FEET. I. H. P., 30,000. DISPLACEMENT, 19,000 TONS

sels depends upon the length, the stability upon the breadth, and the strength upon the depth of the ship. The draught is usually fixed by the depth of water available in docks and harbours at which the vessel calls. It may be interesting to notice here that although the length of the largest vessels has increased about 40 per cent. in the last decade, the draught has increased only about 25 per cent.

The principle of similar structures does not apply in its full extent to ships when size is increased. According to theory, the weight should increase as the cube of the linear dimensions, but in the case of a ship one part of the total weight, viz., that of wood and outfit, increases generally as the square of the dimensions. A number of other items, such as connecting angles, machinery, etc., do not increase as the cube of the dimensions. From these considerations it will be seen that the weight of hull is relatively smaller in the larger vessels, and in this item alone the advantage of the large over the small vessel is immediately apparent.

In the first place the effect of increasing the dimensions of the fuller type of vessels will be considered. Owing to the fullness of the water-lines these vessels usually have great stability, especially in the lighter conditions, and as this varies as the square of the breadth, any increase in this dimension is accompanied by a correspondingly greater increase in stability. It is well known that too much stability in the upright condition, or stiffness, produces a poor sea boat; so from this consideration it is preferable to increase length rather than breadth if a larger vessel is required. The bad effects of great breadth could be counteracted by carrying the heavier cargo high up in the vessel, or adopting the system of 'tween-deck ballast tanks when no cargo is carried; but this is not always possible.

In cases where length and draught are both limited and a greater carrying power is required, the breadth must be



THE FIRST CUNARD LINE STEAMER "BRITANNIA," 1840. LENGTH, 207 FEET; 403 HORSE-POWER; 1139 TONS. TIME OF FIRST TRIP FROM LIVERPOOL TO BOSTON, 14 DAYS AND 8 HOURS

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THE NEW NORTH GERMAN LLOYD TWIN SCREW STEAMSHIP "KAISER WILHELM DER GROSSE." LENGTH, 648 FEET. BREADTH, 66 FEET. DISPLACEMENT, 20,000 TONS. INDICATED HORSE-POWER, 28,000. HIGHEST AVERAGE SPEED, 22.08. KNOTS

increased. This is the case with vessels trading to some of the South American ports, notably Buenos Ayres. The limit of draught there is about 22 feet 6 inches, and the tendency, therefore, has been to increase the beam of vessels upon this service.

The general effect of increasing the dimensions of a given type of cargo vessel, assuming the speed to remain constant, may be seen from the curves in Fig. 1. Starting with a given type of vessel whose indicated horse-power is known for varying speeds, let D be its displacement and S the constant speed of the series; then for any other displacement, D_1, the corresponding speed of the type ship will be $S\left(\frac{D}{D_1}\right)^{\frac{1}{6}}$. If the power of the type ship at this speed be P, the power of the new ship (D_1) will be $P\left(\frac{D_1}{D}\right)^{\frac{7}{6}}$. In this way the power required for a series of vessels of the same form for a constant speed, but varying displacements, may be obtained. This method of dealing with indicated horse-power instead of

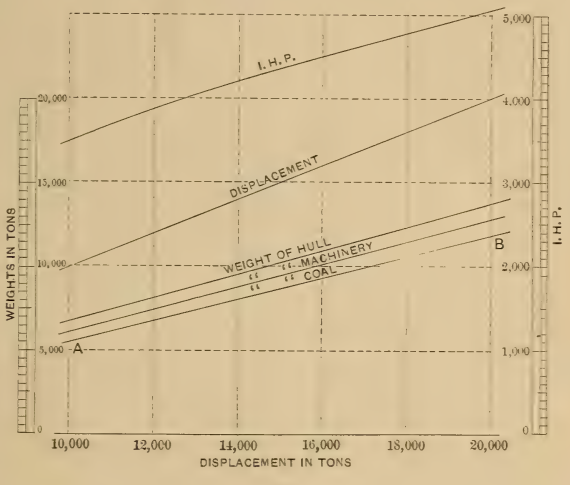


FIG. 1

be obtained; but with slight modifications, the above method may be used. In any case, the curves so obtained will show the general results of increased dimensions, and, if anything, to the advantage of the smaller vessel.

In the curves shown in Fig. 1 the speed of the series has been taken at about thirteen knots per hour and the length of voyage at 3000 knots. The weights of hull, machinery, and coals are set down from the displacement

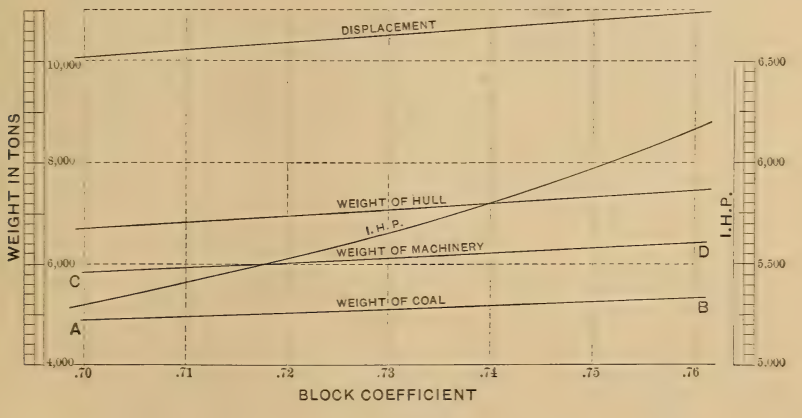


FIG. 2

resistance is more or less approximate.

If the relation between effective and indicated horse-power is known for varying speeds, more accurate results may

curve, and the remaining ordinate between the base and the curve AB gives the amount of weight available for cargo at the various displacements. It will

THE TWIN SCREW STEAMSHIP "PENNSYLVANIA," OF THE HAMBURG-AMERICAN LINE. THE LARGEST FREIGHT CARRIER AFLOAT. LENGTH, 585 FEET. BREADTH, 62 FEET. DISPLACEMENT, 23,000 TONS

be seen that the indicated horse-power increases at a much slower rate than the displacement. For example, starting with a vessel of 10,000 tons displacement and increasing its dimensions so that the displacement reaches 20,000 tons, or an increase of 100 per cent., the power for the same speed is increased, in round numbers, 50 per cent., and the cargo carrying power 120 per cent. The larger vessel has, therefore, a relatively greater carrying power as well as a reduced ratio of indicated horse-power per ton of cargo.

It should be noticed, however, that the above result is true only up to a certain point. When the draught corresponding to a given displacement reaches a certain amount, viz., the depth of water in the ports at which the vessel calls, any further increase in size can take place only in two dimensions, viz., length and breadth, and consequently the full advantages of increased size are, to a great extent, impaired. The breadth in some cases might be slightly increased to make up for the relative loss in draught, but, as was seen above, this is permissible only to a very limited extent.

In general, as the size increases, the sea-going qualities improve; hence the larger vessel is likely to make more regular passages. It is customary in some of the later vessels on certain routes to carry sufficient coal for the round trip, especially in cases where the only coal obtainable at one end of the voyage is very inferior in quality and high in price. In this way, by sacrificing a small percentage of dead weight on one run, a saving may be effected; but this is possible only in large steamers, as the margin available for cargo if the same thing were done in small steamers would be too small.

The curves shown in Fig. 2 represent the general results obtained from increase in "bulk," the dimensions and speed (about 14 knots) remaining constant. The abscissæ represent varying values of block coefficient, and the ordinates, power and weight. The weight of hull increases slightly with increase of block coefficient, and towards the higher values the indicated horse-power begins to increase very rapidly.

There is, however, as may be seen from the curves, an increase in weight available for cargo, within the limits shown, as the vessel is filled out. The curves are plotted in the same manner as before, the ordinate between the base and the curve *CD* representing the total amount of dead weight, and that between the base and the curve *AB* the weight available for cargo, if coal is to be carried, for a voyage of 3000 knots.

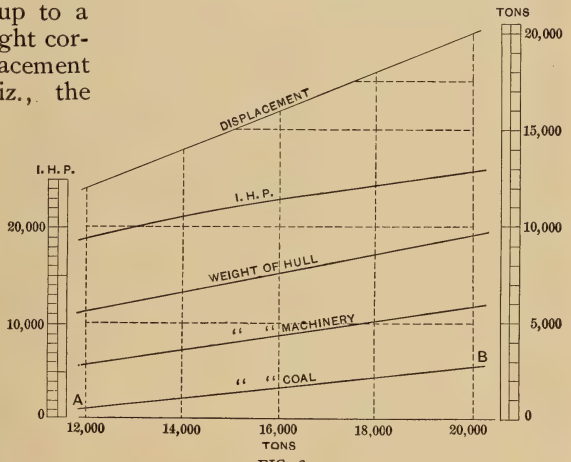


FIG. 3

In this particular case for an increase of 8½ per cent. in the block coefficient there is, in round numbers, 16 per cent. increase in indicated horse-power, and 9¾ per cent. in dead weight. Increase in block coefficient would mean increased first cost, but in certain cases the increased weight of cargo carried might warrant the adoption of the fuller vessel. For any other speed or length of voyage curves similar to those in Figs. 1 and 2 could be obtained, but the dead weight decreases rapidly as the speed is increased. At low speeds the power, and hence the weight of machinery, varies as, say, the cube of the speed, and for a constant length of voyage the weight of coal varies as the square of the speed, or as the two-thirds power of the indicated horse-power.

THE SKYLIGHT OVER THE FIRST CABIN DRAWING-ROOM OF THE ATLANTIC LINER "KAISER FRIEDRICH"

Turning now to fast passenger steamers, increase in size must take place, as mentioned above, in dimensions rather than bulk, although in general the larger vessel may be made slightly fuller than the smaller, to fulfill corresponding conditions. Owing to the fineness of the water-lines, increase of beam is not accompanied by such a great increase in stability as in the case of cargo steamers, but for sea-going purposes this very soon reaches a limit beyond which the vessels will be too stiff. If no increase in stability is required, as the dimensions are increased the ratio of length to breadth should also be increased, assuming the draught to remain constant. In the absolute light condition, most vessels of this type possess little, and in some cases no, stability when upright, and if the beam were increased to overcome this, the stability in the loaded condition would be correspondingly increased and the vessels rendered uncomfortable at sea.

The curves in Fig. 3 show the gen-

eral result of increase in size of vessels of this type, and are plotted in the same way as those in Fig. 1; but in this case the speed has been taken at twenty knots per hour and the voyage at 3000 knots. Owing to the large amount of coal required, the weight available for cargo is very small in the smaller vessels, but increases rapidly as the size is increased.

If a constant amount of cargo were taken for the whole series, the larger vessels could be made finer, or the excess in displacement made up by increased machinery, and a higher speed obtained.

The remaining dimension, namely, depth, is the important factor in both classes for strength purposes. The bending moment increases as the square of the length, other dimensions remaining constant, and the resistance to stresses so produced increases as the moment of inertia of the material in the cross-section.

In some later types the strength has been carried up one deck higher than was customary in the older types, and what was once a light bridge deck is now made an integral part of the structure, capable of taking up the main stresses. The only objection to increasing the moment of inertia in this way is that at the points where the bridge deck ends, unless special care be taken to bring the strength gradually down to the deck below, there is an accumulation of stresses which in nearly every case causes rupture of the plating.

Increase in length is not accompanied by any serious difficulties in the way of construction. The worst condition in which a vessel may be placed is usually assumed to be when she is instantaneously poised upon the crest, or in the hollow, of a wave of her own length. From the results of observations the height of the wave is generally assumed to be one-twentieth of the length, but as waves increase in length the height decreases relatively. Waves over 600 feet in length have been observed, but the height in most cases does not approach one-twentieth of the length, and

THE FIRST CABIN PROMENADE DECK OF THE "KAISER FRIEDRICH"

THE WHITE STAR LINE STEAMER "TEUTONIC." LENGTH, 565 FEET. BREADTH, 57 FEET. DISPLACEMENT, 17,800 TONS

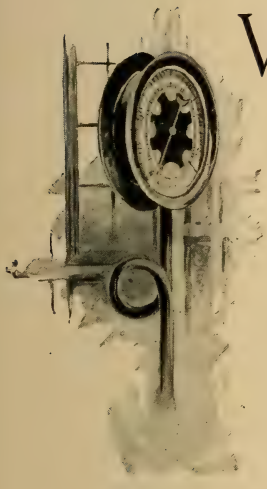
for waves still longer the ratio is still further reduced. From these considerations it may be assumed that vessels over 600 feet in length are not subjected to such severe stresses as the smaller vessels, and therefore the scantlings might be relatively reduced and a further saving in weight effected. This has been borne out in practice by reducing the depth relatively to the length in the larger vessels. The question of pitching requires consideration in these long vessels, but in general the effects of this are purely local and may be provided for without much difficulty.

For speed, cargo carrying, and seagoing qualities, therefore, length seems the best dimension to increase, and at present the limit to this is governed by dry dock accommodation. If larger accommodation for cargo and passengers, and higher speeds are required with the present materials of construction and methods of propulsion, then ships will continue to increase in size; but the limit has been very nearly reached. In the future it is more probable that shipbuilders and engineers will turn their attention to reduction of weight instead of increase in size.

With the adoption of some of the stronger alloys of steel for hulls, the use of water-tube boilers, when these have passed through their term of probation, and some improved form of engine, such as the steam turbine, any further increase in size of steam-ships would be rendered almost unnecessary.

NICKEL STEEL VERSUS MILD STEEL BOILER TUBES

By A. F. Yarrow



WITH the practically assured interest in anything that may tend to increase the durability of water-tube boilers, the writer recently presented to the Institution of Naval Architects, of Great Britain, the results of some experiments which Messrs. Yarrow & Co., Ltd., of London, carried out a short time ago with the view of ascertaining the comparative merits of nickel steel tubes and tubes of mild steel, such as have hitherto been used in water-tube boilers. The nickel steel referred to is an alloy, having from 20 to 25 per cent. of nickel, and in these experiments Messrs. Yarrow & Co. tried to repeat as nearly as possible the worst conditions as regards wear and tear to which tubes in water-tube boilers are subjected.

The deterioration of the tubes is probably owing (1) to the action of acids in the water, due to grease, which, in spite of every precaution, finds its way into the boiler; (2), to the tubes becoming overheated and oxidising on the outside, through contact with the hot gases when passing from the furnace to the uptake; (3), to the action of the steam, which, if superheated, decomposes, causing deterioration on the inside of the tubes. The last two conditions occur when the tubes, from defective circulation, shortness of water, or from the collection of scale, become overheated.

Table I. records what we have termed the "corrosion test." It will be seen that the piece of nickel steel tube *A* was compared with the piece of mild steel tube *B*, the original weights of which were 190 and 186 grams, respectively. Both the tubes were immersed in the same dilute solution of hydrochloric acid for various periods, as indicated. The duration of the tests varied, as shown, from 21 to 168 hours, making a total number of hours for all the trials of 533. The ultimate loss of weight in the nickel steel tube was 5 grams, and in the mild steel tube 98 grams. It will be seen that the original weights of the two specimens in this case did not accurately agree; but in the second trial, *E* and *F*, the tubes were of the same original weight, namely, 188 grams each. The ultimate loss of weight was found to be 7 grams with the nickel steel tube *E*, and 100 grams with the mild steel tube *F*.

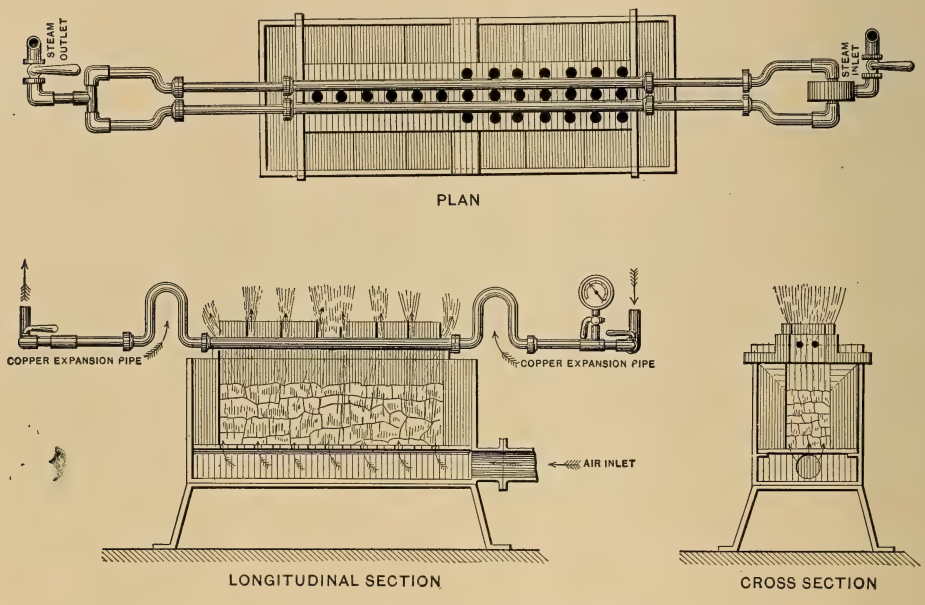
The upshot of the above tests, it will be seen, is that the loss of weight in the first series of tests of the nickel steel tube amounted to 5 grams, being 2.63 per cent., and in the mild steel tube to 98 grams, being 52.68 per cent. In the second series of experiments the loss of weight of the nickel steel tube was 7 grams, being 3.72 per cent., and the mild steel tube 100 grams, being 53.19 per cent. The average loss of weight in the mild steel tube was, therefore, 16½ times what it was in the nickel steel tube.

It may be contended that the relative corrosion of the two specimens when using dilute hydrochloric acid does not correspond with what it would be with such acids as are present in boilers under working conditions, but it is not unreasonable to suppose that it may serve as a guide.

We will now turn to Table II., which records what we have termed the "fire test." This was conducted in the following way:—Two tubes were placed

side by side in a small brick furnace, where they were heated to the same extent, and in every way were practically under the same conditions. The loss of weight of each tube due to oxidation after they had been in a very heated state is indicated by the weights given. It will be seen that the original weight of the nickel steel tube *C* was 192 grams and the mild steel tube *D* was 185 grams. The total loss of weight in this series of tests was, in the case of the nickel steel tube, 47 grams, or 24.47 per cent., and of the mild steel tube 145 grams, or 78.37 per cent. In this case also the original weights of the two pieces of tube were not exactly the same, and we therefore repeated the experiment, as shown by *G* and *H*, in which the weights of the two tubes were identical, namely, 188 grams, and the loss of weight was found in the nickel steel tube to be 52 grams, or 27.66 per cent., and of the mild steel tube 143 grams, or 76.06 per cent. The average loss in weight in the mild steel tube was, therefore, 2.9 times what it was in the nickel steel tube.

These results were submitted to Sir A. J. Durston, Engineer-in-Chief of the British Navy, and he pointed out that the experiments did not accurately conform to all the conditions under which boilers are worked, inasmuch as the tubes, in the case of a boiler when the heating surfaces are not in close contact with the water inside, are subject not only to the action of the gases on the outside, but to that of the superheated steam on the inside. The correctness of this view is unquestionable, and we consequently tested two tubes having a length of 1 foot 8⅝ inches by a diameter of 1 inch outside by 14 L. S. G. This experiment we termed the "superheated steam test." The experiment was carried out in the following manner:—



FURNACE FOR TESTING BOILER TUBES

Two tubes, one of nickel steel and the other of mild steel, were placed side by side in a small brick furnace; at one end of each tube steam was supplied at 60 pounds pressure, it being allowed to issue slowly from the opposite end of each tube, thus insuring the steam being highly superheated. The original weight of each tube was 612 grams. After the experiment had proceeded ten

hours it was stopped, as the mild steel tube gave out, steam issuing from a defective place. The loss of weight in the case of the nickel steel tube was 12.7 grams, and in that of the mild steel tube 85.2 grams. Deterioration in this case is due partly to the action of the steam inside the tube and partly to that of the gases outside.

The loss of weight of a boiler tube from deterioration at the commencement of its life being much less rapid than toward the end of its life, therefore the loss of weight cannot be considered as a quantitive guide for durability, and we continued the superheated steam test as follows:—After the mild steel tube had burnt through and allowed the steam to escape, we replaced it by another similar mild steel tube, corresponding to what would be done in retubing a boiler. The experiment was then continued, and it was found this second mild steel tube gave way and the steam burst through after eight hours, the nickel steel tube still remaining intact. We then substituted this burnt mild steel tube by another tube, and we found that after three hours the nickel steel tube gave out. Every two hours during these experiments the position of the tubes was changed about, not only end for end, but side for side, so as to insure that both tubes were subjected to the same conditions.

The durability of the nickel steel tube corresponded to 21 hours and the mean durability of the first two mild steel tubes to nine hours. I think, therefore, there is a probability that from this cause of deterioration a boiler would require to be retubed two and one-third times as often with mild steel tubes as it would with nickel steel tubes.

In the last experiment the tubes were heated to a bright red, and as it would be unwise to come to any conclusion based upon a single set of experiments,

TABLE I.—CORROSION TEST—EXPERIMENTS TO ASCERTAIN THE EFFECTS OF ACID ON NICKEL STEEL AND MILD STEEL TUBES

Marks and Material.	Original weight in grams.	Two parts water. One part hyhrochloric acid. Duration of immersion in hours. 21	64	44	92	168	72	24	24	24	Total loss in weight during 533 hours.
		Weights in Grams									
Nickel steel, A. N. S.	190	190	189	189	188	186	186	185	185	185	5
Mild steel, B. S.	186	184	173	166	140	101	98	94	91	88	98
Nickel steel, E. N. S.	188	188	187	187	186	183	182	181	181	181	7
Mild Steel, F. S.	188	187	173	162	137	112	95	92	90	88	100

TABLE II.—FIRE TEST—EXPERIMENTS TO ASCERTAIN THE EFFECT OF FIRE ON NICKEL STEEL AND MILD STEEL TUBES

Marks and Materials.	Original weight in grams.	Heated blood red for thirty minutes and allowed to cool.	Heated bright red and cooled in water.	Scale Removed.	Heated straw color for one hour and allowed to cool.	Tubes partly flattened to remove scale.	Heated straw color for one hour and allowed to cool. Scale removed.	Heated straw color for one hour and allowed to cool. Scale removed.	Heated straw color for one hour and allowed to cool.	Scale removed.	Total loss in weight in grams.
		Weight in Grams									
Nickel Steel, C. N. S.	192	192	190	190	171	170	159	151	145	145	47
Mild steel, D. S.	185	184	183	180	130	120	94	68	42	40	145
Nickel steel, G. N. S.	188	188	186	186	172	172	153	142	139	136	52
Mild steel, H. S.	188	188	186	184	147	145	89	58	51	45	143

we repeated it in precisely the same manner, with the exception that the tubes were in this further test only heated up to a very dark red. They were in this trial 3 feet 6 inches in length. The result is similar in character to that obtained when the tubes were heated to a bright red, the only difference being that the trial lasted considerably longer, as the deterioration was not so rapid, on account of the lower temperature. The greater durability of the nickel steel tube, as compared with those of mild steel, was fully confirmed. The nickel steel tube lasted 2.8 times as long as the mild steel tube, and twice as long as the second mild steel tube.

The small furnace in which these superheated steam trials were made is here illustrated, and it will be seen that both ends of the tubes were fitted with copper expansion pipes, the object of which was to allow the tubes to expand and contract freely.

It is a well-known fact that a mild steel plate, or a mild steel tube, when heated and cooled, becomes permanently reduced in length, and this fact must be borne in mind in boiler design, because frequent variations in temperature take place in a boiler owing to the opening and closing of the fire door and the constant varying intensity of the combustion. This permanent contraction during the life of a tube varies according to circumstances, but we thought it well to have some record of its extent when subject to the conditions under which the tubes were placed in this superheated steam test. During the life of one mild steel tube, 3 feet 6 inches in length, heated 21 times to a dull red heat for periods of two hours duration each,—steam passing through the tube at a pressure of 60 pounds,—its length was permanently reduced 56-64 of an inch. The nickel steel tube of the same length, subject to the same conditions, increased 14-64 of an inch.

In the foregoing experiments the tubes were ungalvanised. Had the mild steel tubes been galvanised there would have been a small addition to their durability, the extent of which is a matter of doubt.

We then made some trials with a view to ascertain the relative expansion by heat of the two materials. Two tubes were taken, 22 inches long, 1 inch in diameter, No 16 L. S. G. They were inserted in a large tube and heated gradually up to a dull red for about three-fifths of their length. The tubes were fastened together at one end and projected freely and independently beyond the furnace at the other. A record of the expansion of each of the tubes was made by means of a trammel, and their expansion accurately determined. It was found that the expansion of the nickel steel tube was considerably greater than that of the mild steel tube. It was found that the relative expansion was approximately as three to four, the nickel steel expanding the most. The object of this experiment was to ascertain whether there was sufficient difference in the expansion and contraction of the two materials to cause trouble when nickel steel tubes are placed within a group of tubes of mild steel. The result points to possible risks in this direction, and, should it be desired to place nickel steel tubes in those parts of the boiler where deterioration proceeds with the greatest rapidity, and mild steel tubes elsewhere, this variation of expansion should be borne in mind. I am not prepared to say it is a source of risk, but it is one of those practical points which must not be overlooked.

The tubes corresponding to Tables I. and II. were not quite of the same length, the nickel steel tubes being in all cases somewhat longer than the mild steel tubes, and therefore, so far as this difference in size is concerned, it was unfavourable to the nickel steel tubes, which exposed a larger surface of deterioration.

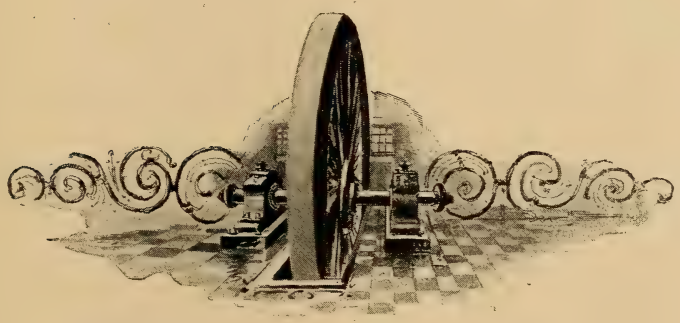
Nickel steel has a ductility almost equal to that obtainable with mild steel, but is considerably tougher in working than the latter; it involves more labour, and causes greater wear and tear of the tools employed in expanding the bell mouthing, to which latter operation we have always attached the highest im-

portance. The ductility does not seem to be impaired by sudden changes of temperature, as shown by specimens which have been bent after being heated and chilled. The tubes upon which our tests have been made were supplied, some by Messrs. Firth and some by Messrs. Krupp.

As regards cost, sufficient has not yet been done to know what the probable ultimate price may be; but, doubtless, it will be reduced from what it now is, if tubes of this alloy are introduced. Even at the present stage, judging from the experiments described, it is not unreasonable to expect that the longer life of the nickel steel will prove fully proportionate to its higher price, if the cost of the more frequent replacing of the mild steel tubes is taken into account; and if this surmise be correct, clearly a decided gain would be obtained by the greater trustworthiness of boilers with nickel steel tubes, and by avoiding the frequent loss of time involved in retubing operations, during which periods the boiler is laid up.

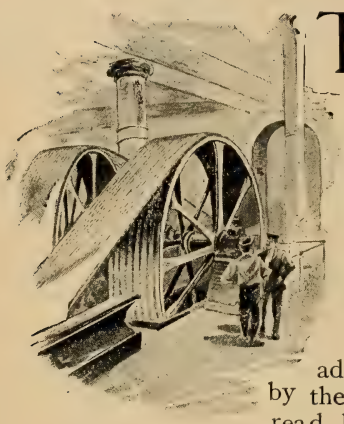
I would observe that we have tried experiments as to the comparative durability of nickel steel having small percentages of nickel, say, up to 5 per cent., and have found that a very slight increase of durability is obtained by such alloys, but not sufficient to render them of any practical value for boiler tubes.

From the foregoing experiments, I think it not unreasonable to assume that nickel steel—20 to 25 per cent. nickel—boiler tubes will have, as regards acid corrosion, a vastly longer life than those of mild steel, and, as regards deterioration from the action of heated gases or steam, at least twice the durability of mild steel. Before concluding, I should like to mention that these experiments were carried out in consequence of our attention having been drawn to the probable advantage of nickel steel tubes by Mr. Andreæ, the engineer-in-chief of the Dutch Navy.



CONDENSING PLANTS FOR FACTORY PURPOSES

By Sir Alfred Seale Haslam



THE application of condensers of various kinds to steam engines dates from the time when the celebrated engineer, Watt, took out his patent for an injection condenser. The older system adopted, as detailed by the author in a paper read before the Engineering Conference of the British Institution of Civil Engineers, was the application of a condenser to each separate large engine, leaving the medium and small-size engines without condensers; but in many modern installations, where a large number of various-size engines are used in connection with the works, or more particularly in electric light stations, it is found advisable to have one large condenser to receive the steam from the various engines which may be distributed over the works or installations. In cases where this arrangement is not carried out, a large number of engines are frequently left unprovided with a condenser, the result being increased working expenses in coal consumption. A large condenser tends to economy and efficiency, and also to a reduction in first cost and economy in maintenance. Careful tests have been made at factories where engines have worked without condensers, and by the application of a condenser common to a large number of engines an economy has been secured amounting to 20 or 30 per cent. in the coal consumption. On board ship these condensers are found to be of immense value.

The old practice was to convey the steam to the condenser of the main engines, but when the steamer is in port and the main engines are not at work, the auxiliary engines for electric light, refrigerating machinery, winches, cranes, and various engines used on board ship must either work high-pressure or exhaust into the main condenser without a vacuum.

By having a separate condenser fitted with an air pump, into which all the various engines can exhaust their steam, the condensed steam is available for feeding the boilers, the efficiency of the engines is maintained, and a reduction in coal consumption is the result.

Condensers may be divided into four classes or types:—

First, the injection condenser.

Second, the ejector condenser.

Third, the submerged or closed surface condenser.

Fourth, the evaporative or open-air condenser.

The first type or injection condenser, in construction and working, is for all practical purposes the same as when patented by Watt, consisting of a condensing chamber with spray or injection pipe, air pump, and hot-well. The advantages of this type are:—Simplicity in construction, fewness of working parts and non-liability to get out of order, easy cleaning, and cheapness in first cost. This condenser, however, has several disadvantages. Unless the condensing water available is of good quality the hot water cannot be used for feeding the boilers; thus the condensed steam is lost; neither is it possible to obtain so good a vacuum with an injection condenser as can be obtained from a properly constructed immersed surface condenser. The working of this class of condenser is as follows:—Steam en-

ters the condensing chamber where it comes in contact with a spray of cold water, which absorbs the latent heat and condenses the steam into water. A considerable volume of air is brought over with the steam, some with the injection water and some also is due to leakages. To remove the air and water a pump is provided, necessarily of larger capacity than that used for a surface condenser, seeing that both the air and water have to be removed; this pump delivers the water into the hot-well and the air is discharged by a pipe. The designs of pumps and condensers of this type are very numerous. Some are vertical pattern fitted with single or double-acting air pumps; others are horizontal pattern fitted with single or double-acting air pumps. Both bucket and displacement pumps are used according to the ideas of different engineers.

The second type, or ejector condenser, is a modification of the ejector for boiler-feeding purposes; no air pump is required. The mode of working is, briefly, as follows:—Exhaust steam from the engine enters the ejector at a very high velocity, meeting about twenty times its weight of cold water passing through the jet at a lower speed, this velocity causing a momentum sufficient to convey the water, steam, and air into a water-sealed discharge pipe or hot-well. Any rotation of the water is objectionable. The condensation of steam is dependent upon the length of the water and steam columns to produce an efficient vacuum. The objection to this style of condenser is that unless the water is good it cannot be used for boiler-feed purposes. Furthermore, this form requires careful adjustment, and unless this be accurately done, the ejectors cannot be depended upon to keep a steady vacuum. These condensers are not considered very reliable, because a little dirt or obstruction will clog and impede the flow of water; when this happens the exact areas which are regulated by cones are interfered with, and this prevents efficient working. As a rule, the vacuum obtained is not high,—approximately, one of 14 inches to 18 inches may be relied upon.

The third type, or immersed surface condenser, is more expensive than the other two classes mentioned, but is considered the most efficient, and the great benefit derived from it, as applied to marine purposes, cannot be overestimated. This condenser was invented by Samuel Hall, of Basford, Notts, about 1840, and was first applied to the steamer *Hercules*, running between Cork and Liverpool. An account of it was given in the *Mechanics' Magazine*, of July 18, 1840, and it is very remarkable to note that Mr. Hall admits that when he introduced this condenser it met with most serious opposition on the part of the marine engineers of that day, showing how little they appreciated the importance of the invention which was destined to prove of such great value to marine engines in the future. The general construction of this type of condenser is as follows:—

A number of solid-drawn copper or brass tubes are enclosed in a casing, generally made of cast iron, and are supported by end-plates. In the early types the tubes were expanded with a drift, and later by an ordinary tube expander, but it was found that frequent leakage occurred, and when the tubes required to be examined, they were seriously damaged at the ends by being removed, and often unfit for further use. At a later period wood ferrules were introduced, but these were found not altogether satisfactory, owing to the leakages which arose from time to time.

At the present time the most approved manner of securing the tubes in the end-plates is to drill the end-plates and form a stuffing-box on the outside of each. This stuffing-box is screwed to receive a gun-metal nipple or gland, which may be packed with cotton or other suitable material; the gland is then screwed hard on the packing, and this makes a perfect joint and prevents leakage.

When the glands are slacked back, the tubes can be easily removed for examination, and replaced without difficulty and at a nominal cost. A difference of opinion exists as to whether the tubes ought to be made of solid-

drawn copper or brass. The author's experience is that if the tubes are properly tinned, it is not of any great importance which material the tubes are made from. It is well known that distilled water has a strong action on both copper and brass.

The air pumps used in connection with this class of condenser are the ordinary vertical or displacement types, the ordinary being generally single-acting, the displacement double-acting. The water-circulating pumps may be ordinary piston type, but centrifugal pumps are very largely adopted, the latter being driven by a separate engine.

The method of working these condensers is extremely simple. The exhaust steam is conveyed from the engine, admitted to the casing of the condenser and plays upon the outside of the tubes, cold water being circulated through the tubes by a pump, as described. The condensed steam is drawn away with the air and delivered into the hot-well. A feed pump is generally attached which conveys the condensed steam back to the boiler. In order to obtain the best results, however, great care should be taken with the design, so that the steam is properly distributed over the entire tube surface; if this detail be not carefully attended to, the steam will often make a short cut or passage to the air pump without being properly condensed, and should this be the case very frequently the vacuum is 5 inches to 6 inches below what it ought to be.

It is usual in designing condensers for marine purposes to give rather larger surface per indicated horse-power, in order that the condensers may not fall off to any material extent in efficiency when the boats are passing through the tropics.

There are many advantages in using and working this type of condenser. First, any kind of water can be used for condensing purposes. Secondly, the heat of condensation is utilised to advantage by feeding with water raised to a high temperature. Thirdly, fuel is saved because it is not necessary to blow off the boilers so frequently in order to remove the sediment or accumulation of dirt. Fourthly, the size of boiler can be reduced owing to the fact that hot feed-water is used for boiler-feed supply. Fifthly, the life of the boiler is prolonged by reason of the fact that it is kept free from scale or accumulation of dirt.

On the other hand, there are some drawbacks; an additional pump is required over and above what is needed for the injection condenser. The space occupied is greater than that required for the injection condenser. The tubes of the condenser require attention and cleaning in order to maintain the best results and the highest efficiency. The first cost of the immersed surface condenser also is greater than for the injection condenser, and a larger amount of condensing water is required, as the interchange of heat is not so thorough as in the injection type in which the water and steam come in contact with each other.

The fourth type, or evaporative or open-air surface condenser, was first used by Messrs. Pontifex & Wood, Limited, engineers, of London, about forty or fifty years ago, and patented by that firm, who made a number of these condensers for sugar refineries, not only abroad, but also at the East End of London. Such condensers have been used in connection with vacuum pans and steam engines. For a time this type of condenser was rather neglected, cheaper forms of condensers being used; but where a limited supply of water only is available these condensers are absolutely necessary. During the past few years the attention of engineers has been drawn to this particular type of apparatus, and it is now being made in various forms by different engineering firms. The condenser first made by Messrs. Pontifex & Wood had large round copper pipes, about 4 inches in diameter, secured at each end into a copper diaphragm, the said diaphragms being made in sections, each for about ten 4-inch pipes; the diaphragms were about ⅛-inch thick, and being of this thickness, effectually provided for expansion. They were secured to D-shaped cast iron boxes made the same length, the ends of which were flanged

for bolting together endways. Messrs. Pontifex & Wood, before the expiration of their patent, found by experience that smaller pipes were more effective, and the size was reduced from 4 inches in diameter to 2 inches in diameter, and instead of placing cast iron boxes or standards at each end, they placed the box at one end, connecting the pipes together at the opposite end by a horseshoe bend, thus providing for expansion, and giving the steam a longer travel or passage through the tubes.

When possible, the condensers were placed on the top of the building in an exposed situation, in order that they might obtain the full advantage of a current of air, as it was found that the vacuum obtained on a windy day was much better than on a day when very little breeze was available. These facts have been fully recognised of late by many engineers, and have led to the extended use of fans, which materially reduce the water consumption and improve the efficiency of the condensers.

The amount of water used by these condensers varies according to the circulation of the air, and is only about one-thirtieth the quantity of that required or used in an immersed surface condenser. Various forms have been adopted for the evaporative condenser, some being made of cast iron, others of wrought iron, copper, and brass. One type of condenser consists of cast iron pipes arranged vertically, the upper part of the pipes being jointed together by horseshoe bends, and the bottom ends jointed or secured to a cast iron box common to all the pipes. Other condensers have wrought iron pipes, arranged horizontally, but unless these are galvanised, or otherwise protected, decay rapidly takes place; in fact, even with proper galvanising the life of these condensers is very limited. Experiments have been tried by placing inside the tube a device for splitting up or distributing the steam. Other engineers use corrugated tubes, with the surface partially flattened, to effect the same purpose.

With regard to the use of copper tubes in this type of condenser, it should not be forgotten that one square foot of surface in copper is worth more than double the amount of surface in iron.

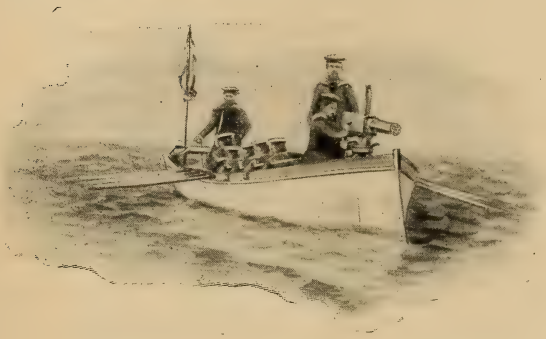
With regard to the various forms, or external shape of the tubes, any deviation from the round form causes trouble because of difficulty of cleaning. The plain round form of tube is the easiest to keep clean. It is very difficult to get condensing water free from lime or other substances which may deposit on the surface of the tubes, and if such deposit be allowed to accumulate, the efficiency of the apparatus soon becomes impaired.

The main principles to be studied in the consideration of an evaporative surface condenser are simplicity of form, a sufficiency of surface, carefully designed joints, carefully made with special tools. But even when the greatest care is exercised on account of the number of joints, the vacuum obtained is not generally so good as that obtained by the immersed type of surface condenser.

TRIPLE SCREWS FOR WARSHIPS

By Rear-Admiral George W. Melville, Engineer-in-Chief of the United States Navy

There has been, for a number of years, no more able exponent of the advantages of triple-screw propulsion for war ships than Rear-Admiral Melville, and his recent paper on the subject, read before the Institution of Naval Architects of Great Britain, admirably presents them. At the request of the editor, it was, therefore, specially revised by the author for publication here, and illustrations as well were added of some of the notable triple-screw ships of different navies.

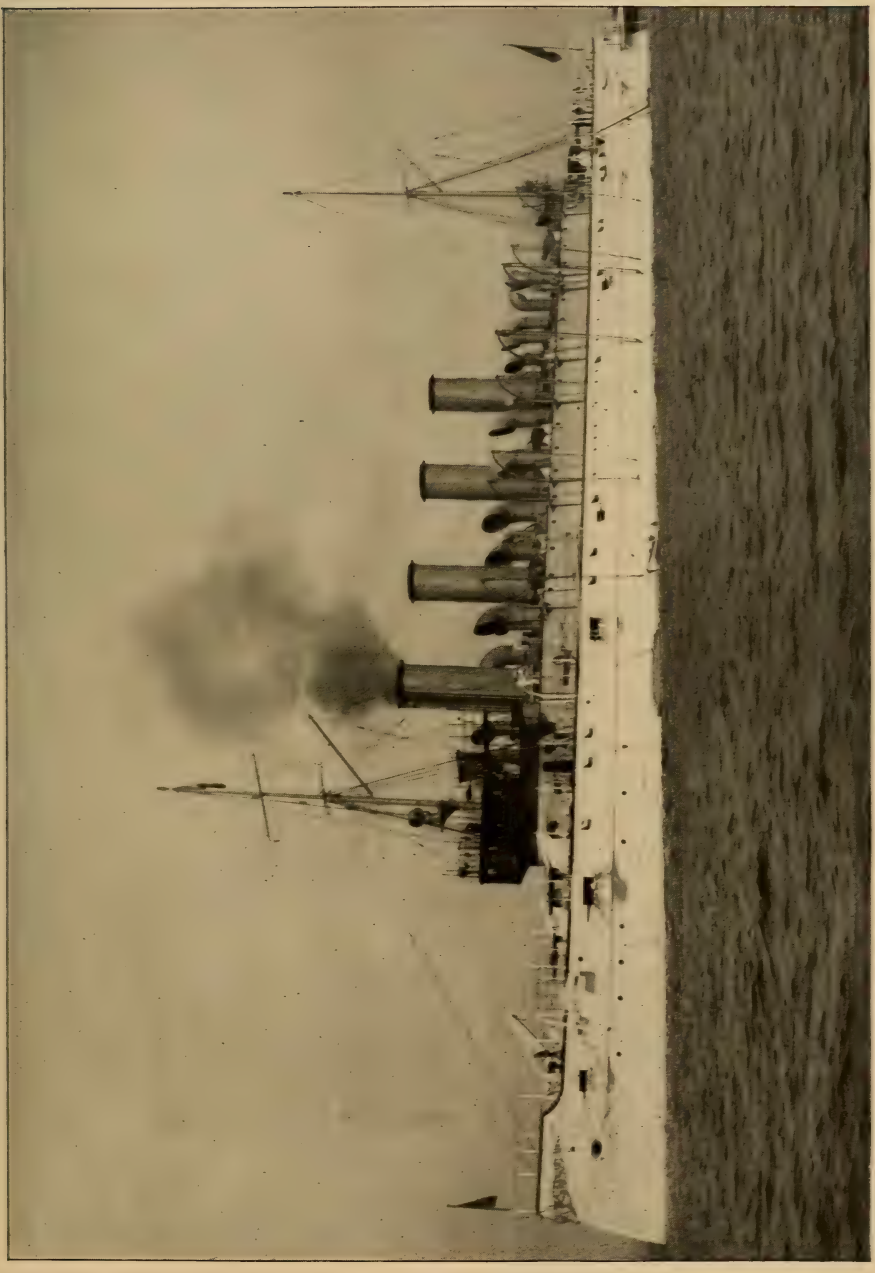


IN the preparation of a set of tables showing the power required to drive a vessel of a given displacement at a given speed, data have been used which were gathered from the results of about two hundred trials of nearly as many ships. From this set of tables the remarkable fact was developed that the propulsive efficiency of vessels with three screws is, in almost every case, above that of ships of approximately the same size, speed and general lines, but fitted with only two sets of engines. Attention has heretofore been drawn to the remarkable performance of the United States cruisers *Columbia* and *Minneapolis* on their trials. Recently, as the number of high-speed ships has increased so greatly, it has been very interesting to those who were responsible for the plans of the machinery of these vessels to see how well they have maintained their position in the front rank of all naval vessels. These five-year-old ships, ten years old in design, are still among the most economical vessels in the world's navies so far as propulsive efficiency goes.

There are many reasons for the superiority of the *Columbia* and *Minneapolis* over other vessels of the United States Navy built at about the same time. The stream lines of these ships are remarkably easy and the resistance is low, these factors giving,—it is claimed by many, a—total resistance below that calculated from results of trials of less carefully designed ships. This is no doubt true to a certain extent, but comparison between these American ships and those of other nationality, but of approximately the same lines and speed, shows still the superior efficiency of these vessels. The main cause of this increased efficiency lies in the use of three engines and propellers for the motive power. Not only has the propulsive efficiency been benefited, but there are so many engineering and tactical advantages arising from the use of triple screws that it may be readily seen why so many ships are now designed for this system of propulsion.

The advantages due to the use of three propelling engines instead of two have been pointed out before, but it may be of interest to recall some of the reasons leading to the adoption of this system for the *Columbia* and *Minneapolis*. It was not possible, at the time of the design of those vessels, to obtain, in the United States, sufficiently large forgings for such great power as it was desired to install, if the twin-screw system were adhered to. Other chief factors were the greater safety of the machinery and of the ship due to the use of three screws, as well as the, then conjectured but now proven, increased economy due to the use of triple screws.

To-day we have a somewhat different



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THE UNITED STATES TRIPLE-SCREW CRUISER "COLUMBIA." LENGTH, 412 FEET. BREADTH, 58 FEET. TRIAL TRIP SPEED, 22.8 KNOTS WITH 18,509 I. H. P. DISPLACEMENT, 7,350 TONS

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THE RUSSIAN ARMORED TRIPLE-SCREW CRUISER "ROSSIA." LENGTH, 480 FEET. BREADTH, 68 FEET. DISPLACEMENT, 12,130 TONS

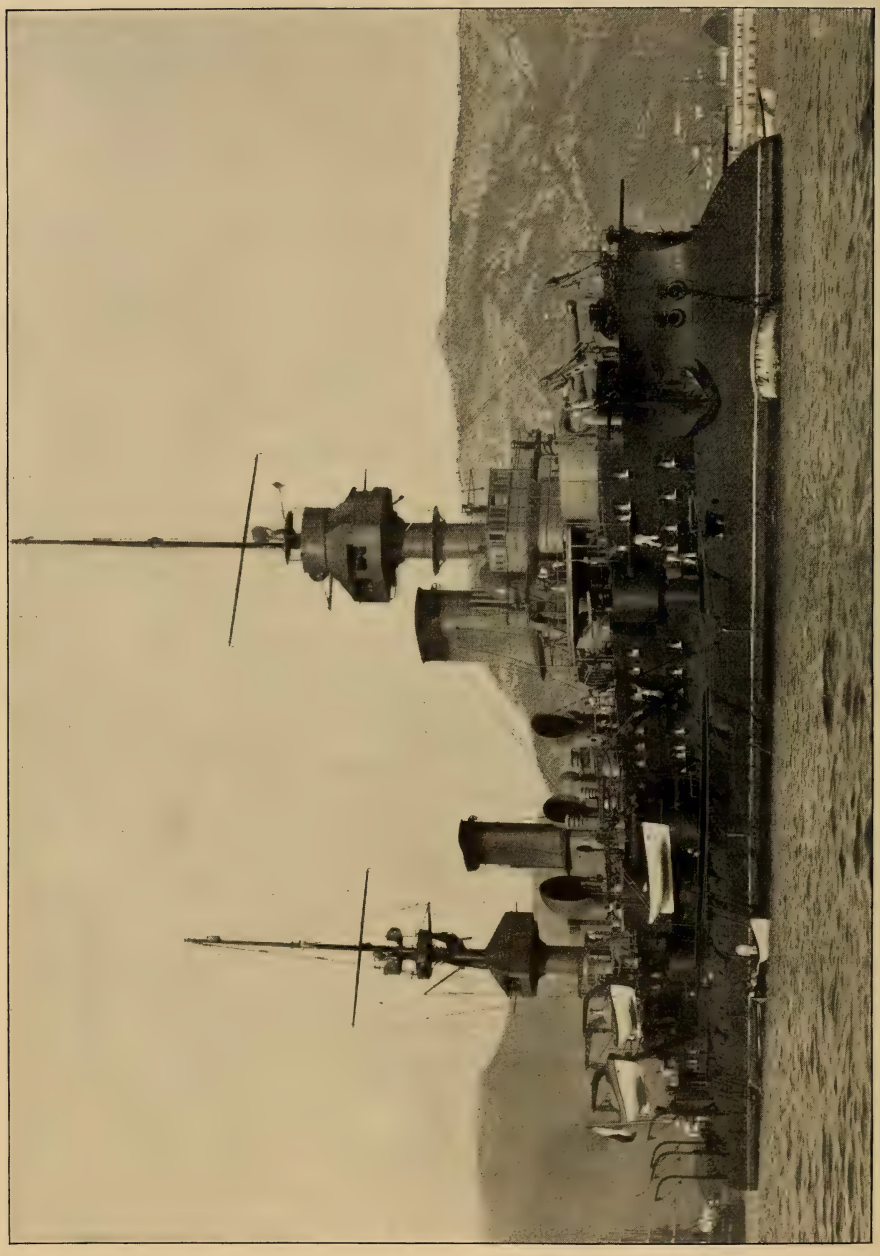
case presented in the design of high-powered cruisers or battle-ships. The conditions have changed. We are confronted no longer by the probable inability of the steel manufacturers to furnish forgings and castings of any size we may desire for any power yet designed to be installed in a man-of-war. On the contrary, we have examples of engines of about the power we desire to use for our fastest ships already constructed in the United States and giving complete satisfaction, not only to the designers, but also to the builders and to the owners. The science of metallurgy has made such progress in the last decade that we are now able to specify regularly steel of 95,000 pounds tensile strength, 21 per cent. elongation in 2 inches, and to stand cold-bending to an inner diameter of 1 inch without showing cracks or flaws. Improved methods of forging, more thorough knowledge of fluxes, the exclusive use of nickel steel for high-grade engine construction, the judicious employment of annealing and tempering,—all these, combined, enable us to secure stronger materials and obtain a vast increase of power without a much greater weight than that required, ten years ago, for the lower powers then prevailing. The reduction in weights is most apparent in the moving parts. This is an important point, as it has meant that the growth in power has not been accompanied by an increase in vibration,—a matter that is likely to limit speeds of rotation in the future. We are no longer forced to divide the power among three shafts because of the impossibility of obtaining one sufficiently large to transmit half the power. We can now secure all of the materials needed for the machinery of the highest power yet planned.

There are many other considerations, however, both tactical and engineering, which make it still advisable, at least for the highest powers, to use the triple screw method of propulsion for men-of-war.

The most evident advantage from the use of three screws is the consequent subdivision of the power. This is of particular moment on war vessels where the possibility of disaster in battle is to be considered as well as that of accident in time of peace. Not only does the increased number of engines decrease the probable amount of power that may be disabled at any time, but the chance of fatal injury to the ship through its motive machinery is also greatly lessened. The danger from a shell is decreased. It would require three shots penetrating the steel deck to completely disable a triple-screw ship, as against but two in the case of a vessel fitted with twin engines. This, however, is assuming a possibility which may not be a fact, that a shell will not have any disastrous effect outside of the compartment in which it explodes. It is probable that the vertical bulkhead between the engine rooms cannot be so entirely depended upon as to restrict the effects of an explosion. It is quite possible that a single, very lucky, shot might completely disable a twin-screw war vessel. If so, then it would take at least two such shots to inflict corresponding injury on any ship with triple screws. In case of the wrecking of any single engine, the amount of power lost with twin screws would be one-half, as against the much less reduction of one-third in triple-screw ships.

It may be urged,—and with justice,—that the engines of men-of-war are already well guarded from shell fire. If it can be shown, however, that the protection can be increased without consequent loss in other directions, it will surely be well worth while to adopt the system affording greater security. In the old days of sailing ships many a battle was won, sometimes against superior force, by the disablement of the sail power of one of the combatants. After the motive force of any fighting ship was gone she was at the mercy of her foe. In our time, when battle-ships have a fair all-around fire, the likelihood of this is somewhat reduced; but it is still apparent that any ship which is inert upon the sea is far the inferior of her dirigible enemy. Any system which increases the chance of securing and keeping the "weather gauge" in battle must be good.

Should one of the propelling engines



THE FRENCH TRIPLE-SCREW TURRET SHIP "MASSÉNA." LENGTH, 360 FEET. BREADTH, 66 FEET. DISPLACEMENT, 11,900 TONS. I. H. P., 12,600

be disabled, there is not nearly as much interference with what is called the handiness, the steering qualities, of the ship, if there are three screws as if there be but two. With twin screws, and one only in use, it is necessary, in order to keep the vessel on her course, to use a helm angle of from 6½ to 10 degrees. This is the amount when the screw of the idle engine is left to revolve freely. We have attempted to get over this difficulty by using diverging shafts and thus reducing the turning effect of the engines, but this is objected to by the deck officers who wish vessels which can readily "turn on their heels." Of course, the less the fraction of the power that is disabled, the less the ill effect on handiness.

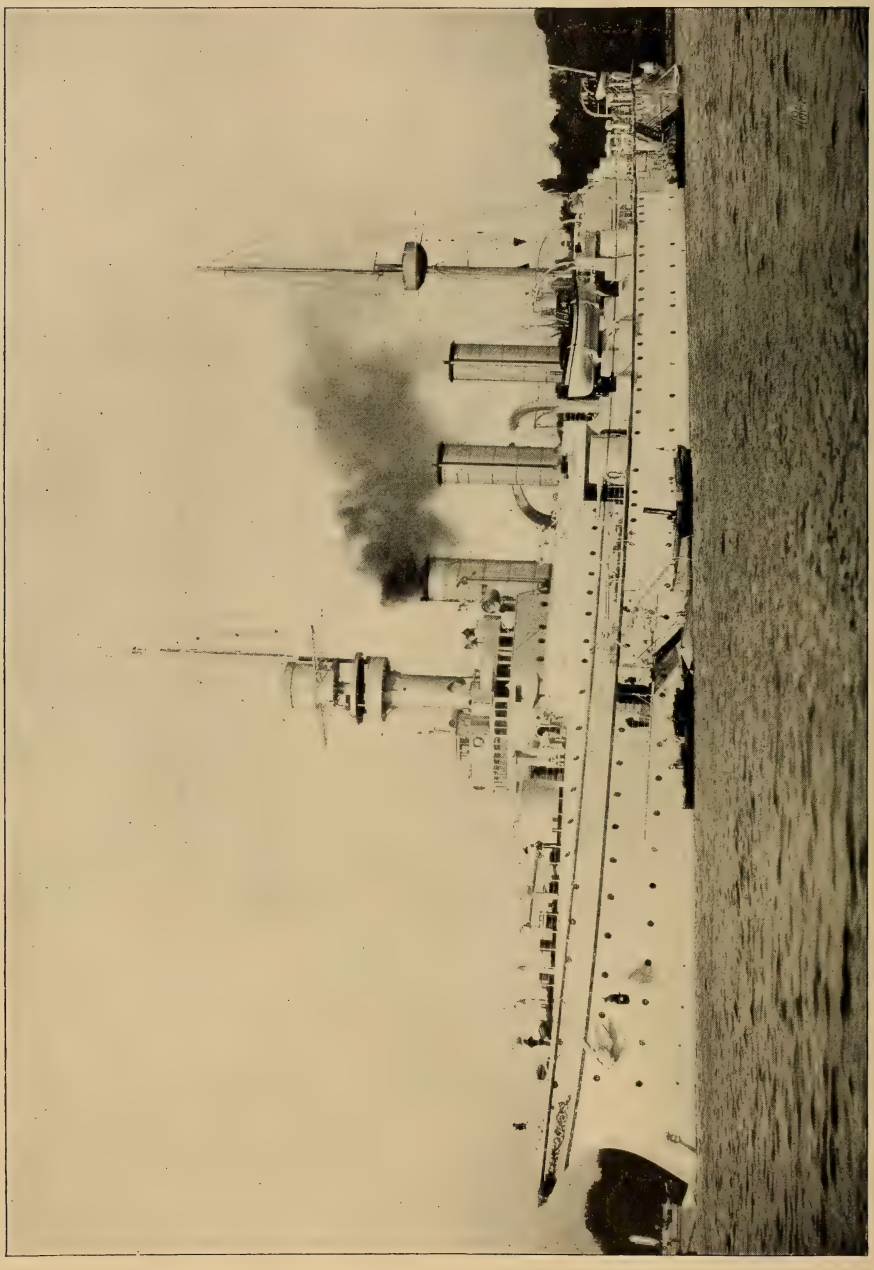
For war vessels it is desirable to make the water-tight compartments as small as possible. The reduction in the smaller sizes of engines in three-screwed ships leads to this end, and, as will be pointed out later, this is effected with no increase in the total engine-room space. One of the greatest advantages from the use of triple screws is that smaller propellers are required for the same total power. This particular, in itself, presents sufficient advantages to justify the use of three engines on warships,—advantages which are so practical, engineering and tactical, that it is surprising that this point has not been more thoroughly developed.

A very large part of the loss of power at the propeller is due to the frictional resistance of the water to the passage of the propeller blade. This resistance increases with any increase of the peripheral speed of the blades, and low speed will be advantageous in this regard. It is assumed, of course, that due account is taken of the ratio between the pitch and the diameter of the screw. If this ratio be not unreasonably increased, however,—and with the large hubs used in current designs this ratio may be profitably rather high,—it will be a great gain from an economical standpoint to reduce the peripheral speed. With very high speeds and powers this speed is now very near the critical point beyond which the friction is excessive, and the effects of cavitation begin to be felt. The decrease of pressure upon the forward sides of the screw blades, at high velocity, is not a negligible quantity. The matter of proper propeller design is too complicated to be more than glanced at here, but it must be evident that to reduce the peripheral speed would be advantageous in the cases of the screws of large diameter necessary in the application of very high powers. Now, the use of three screws allows a reduction in diameter of screw of over 20 per cent., and while, as will be pointed out, this is accompanied by an increase in the number of revolutions, the speed of periphery may readily be reduced below what is required in twin-screw practice.

At the stern of the ship, amidships in the following wake, always present to some extent with the most carefully designed hulls, the effects of a large screw are not so signally bad. I think that "cavitation," or the tendency thereto, is greatly reduced in this following wake, and, on that account, I believe that a considerably greater efficiency is obtained from the screw at the stern post than from those on the quarters. Whatever the cause, this increase in efficiency is so well shown by the results of trials that it can no longer be questioned. I mean, of course, the trials of large ships, not tank experiments. The latter serve very well for determining the actual resistance of a hull, but not for fixing the economy of propulsion, or the ratio between the towing and indicated powers. It is in the increase of efficiency and not in any decrease in resistance that the economical advantage of triple screws must be found.

No test of a propeller can be held to have so much value as a test upon ships. Model experiments of propellers are not satisfactory. It requires experiments with the full-sized screw, working at the designed pitch and at its designed speed, under its full load of work, to give us conclusive results. Trials under these conditions show, as I have said, a considerable advantage, due to the use of triple screws.

Investigation along this line has not



THE TRIPLE-SCREW GERMAN PROTECTED CRUISER 'HERTHA

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yet proceeded far enough to enable me to give more than tentative figures as to the propulsive efficiency due to the different methods of arranging the screws. It is, however, certain that there are gains from both the use of small screws and of a screw working in the following wake, and that these gains would naturally grow with an increase in speed. Speaking only of full-power trials, it will probably be found that, up to some low speed not yet determined, it will be best, from the economical standpoint only, to use a single screw; beyond this point, data of many ships fitted with the different methods of screw propulsion.

I have discussed this point at considerable length principally to develop the following conclusions:—

1st. The use of triple screws leads to a considerable economy at the highest speeds.

2d. Decrease in size of screws is peculiarly economical as regards the wing screws, and

3d. To evenly distribute the ill effects of high peripheral speed, and to take advantage of the following wake, the

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THE GERMAN BATTLE-SHIP "KAISER FRIEDRICH III." THREE SCREWS

it will be found that the use of twin screws would tend to a reduction in the power required for a given hull and maximum speed, and that, at any time, where twin screws are good, triple screws are better. I estimate the average economy over single-screw ships, from the use of twin screws, as about 8 per cent. for vessels of maximum speeds from 12 to 20 knots, and I consider that triple screws are more economical than twin screws by from 5 per cent. for 15-knot ships to 12 per cent. for those of 24 knots speed. These figures are approximate, but they are from trial

centre screw should be made larger than the wing or side screws.

But there are many other advantages due to the smaller screws, particularly the smaller wing screws, and especially for men-of-war.

In ramming an enemy, if all goes well, there would be little difference between the twin and triple systems, but a glancing blow from either forward or aft would certainly take off the enemy's side screw if, as in twin practice, it projected beyond the counter; and, later on, as the ships rubbed past each other, one's own side screw would be broken, under the

same condition of projection. But, with a small screw, such as can be had in the triple system, neither propeller would be damaged, and the stern screw would be safe in any event. This point is of value, too, in ordinary cruising where a floating log, or a pile in a river, would disable a propeller of a twin-screw ship, while the obstruction would have been pushed clear of the smaller propeller of a triple-screw by the ship's hull. Going alongside dock also,—that bugaboo to commanders of high-powered, fine-lined, speedy twin-screw vessels,—would be made much easier.

The shorter shafting required for getting the smaller propellers clear of the ship would allow these screws to be placed further forward, where they would be better protected by the hull. This shorter shafting would also decrease the strains on the propeller shafting in bad weather, and would often obviate the necessity of an extra supporting strut, giving, as well, a decreased danger of fracture and the possibility of decreasing the weight.

The fact that with smaller screws the tips of blades are lower in the water than with the twin-screw system gives advantages. The design of the upper and fuller stream lines could be considerably freer. If it is considered advisable (and I have no doubt the hull designers will show that this gain is not of great moment where a central screw is fitted), this advantage could be passed over in favour of giving the wing shafting a slight inclination upward, so as to obtain a horizontal thrust when the stern of the vessel settles in the water, at full speed. Ordinarily, however, the squatting of the ship would be insignificant. The fact must not be overlooked that the lower propellers are placed, the freer the access of water, and the more perfect the action of the screw.

With tips of blades well buried, the danger of racing is decreased, each extra foot of immersion reducing it. Any one who has stood by the throttle, checking the engine with the heave of the ship, appreciates fully this advantage. The central screw, of course, would never race except in a sea where the ship was pitching heavily; while the side screws, being well forward and deep in the water, would probably never give trouble in the worst of seas.

When the use of three screws was first proposed, the idea prevailed in the minds of most engineers that the "race" of the water from the side screws would materially affect the action of the central screw. The error of this supposition was fully shown by the trials of the *Columbia* and *Minneapolis*. In the *Columbia* the pitch of all screws was made the same. The trials of this ship having shown the revolutions of the central screw to be less than those of the wing screws, the pitch of the central screw on the *Minneapolis* was made 6 inches less than that of the side screws. On the trials of the latter vessel the speed of rotation of the central screw was almost precisely a mean between the speeds of the two side screws, which differed slightly in pitch. This result was obtained without any "jockeying" of the throttle or change in the cut-off.

Attention has been called to the feasibility in the triple system of securing a greater number of revolutions owing to the reduction in diameter of the propeller giving decreased friction of the blades. This matter of increased speed of rotation affects directly the efficiency of the machinery, especially in warships where the stroke of the engine is limited by the height below the protective deck. The piston speed must be high to get the required power from modern machinery without too cumbrous low-pressure cylinders. Any increase in piston speed, or in the number of revolutions, decreases the condensation in the cylinders, as the item of time is one of considerable importance as far as this condensation is concerned. And, further, as a consequence of greater piston speed, we obtain lighter engines and shafting. For small powers it is generally possible to obtain great piston speed in low naval engines by a great number of revolutions; but there has been pointed out the difficulty of obtaining efficient propellers at high rotative speeds for transmitting great powers. We know, of course, that it is possible to get an effi-

cient propeller for the very highest powers yet used; but these propellers must be of great diameter in large ships. It is not easy to secure a screw that will be efficient, and that will fit on a 22-knot, 12,000-ton ship of no more than 24 feet draught. There must be a certain minimum immersion of the screw blades, and this must be greater for twin-screw than for single-screw vessels, because of the rolling of the ship. It is necessary also to have a considerable difference in level between the keel and the lowest part of the screws in a twin-screw vessel. It will surely be difficult, and, I believe, impossible, without the use of high glacis plates, to obtain satisfactory machinery for twin-screw ships under the conditions named, 22 knots, 12,000 tons and 24 feet draught.

In the design of marine machinery it is important that the ratio between the stroke and the diameter of cylinders be kept sufficiently high. This ratio is necessarily low in all naval vessels, as compared with the merchant service on account of the necessity of keeping the machinery below the protective deck. Of course, the larger the power and size of the low-pressure cylinder, the longer the stroke should be, and therefore the greater the height of engine room required for a properly designed engine. The greater the draught, the greater the possible height of engine-room, and, for the same number of revolutions, the greater the piston speed. It is unquestionable that, where more than, say, 10,000 horse-power is to be transmitted through a single shaft, under present conditions of speed and displacement, the number of revolutions will be limited by the propeller.

It has been shown that the use of triple screws would tend to a decrease in the volume of the cylinders required for giving the power. This is quite apart from the fact that the power is divided into three parts instead of two, and is due to the greater piston speed possible with the smaller screws. It will be seen, then, that considerably more latitude is allowable in the design of machinery for ships with triple screws than would be possible if twin screws were used. If three engines are installed, it is certain that a less height is required under the protective deck than would be necessary for a twin-screw ship.

It is to be noted, then, that the economy of a triple-screw ship is developed not only in more efficient propulsion, but also in the more efficient use of the steam in the engines due to the decreased condensation following the increased number of revolutions and the greater piston speed. The economy of propulsion is thus increased as a result of both increased propulsion efficiency and of increased efficiency of the engines. A decreased total weight of the machinery is also a natural result of the use of triple screws.

It is, of course, a fact that the use of three engines multiplies the number of engine parts. The resulting disadvantage is, however, much more apparent than real. The *Columbia* and *Minneapolis* are examples of the practicability of installing large power in three 3-cylinder engines, and this was accomplished with a stroke of but 42 inches. There is no doubt that it would have been necessary to use 4-cylinder engines, at least, if twin screws had been used. The absolutely necessary increase in the number of cylinders is thus shown to be but one-eighth. Of course, it is understood that the use of 3-cylinder engines is not now generally approved. It is merely pointed out as feasible, and as intended to show that the arguments against triple screws, based on the multiplicity of engine parts, could readily be made of practically no weight, if other conditions did not render advisable an increase in the number of cylinders.

Water-tube boilers have now come to stay. These bring with them steam of high pressure and cause the use of quadruple expansion engines for economy's sake. At 200 pounds pressure the quadruple expansion engine gives sufficient gain to justify its employment. Owing to the low powers of peace-cruising with men-of-war, it is questionable whether it is desirable, with these ships,

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THE FRENCH TRIPLE-SCREW CRUISER "DUPUY DE LÔME." LENGTH, 374 FEET. BREADTH, 51 FEET. DISPLACEMENT, 6297 TONS. I. H. P., 14,000

to design engines for the greatest economy at the highest powers. Unquestionably an arrangement of cylinders which gives the greatest economy at the highest powers produces a markedly uneconomical engine for the lower powers ordinarily used in peace.

The wide variations in present designs show how different designers view this problem. It is extremely complicated, and I am free to confess that much more data than are now available are needed for a full solution. We must know the cost of running the auxiliary machinery, and not only the average power of the main engines, but their range of power must also be carefully considered. It has been thought advisable, however, in the design proposed for the latest fast ships of the United States Navy to use quadruple expansion engines throughout, using 13 cylinders in all in the three main engines. This is a considerable change from the practice of 25 years ago when two cylinders were most frequent. But the fact that this large number of cylinders has been adopted shows that our experience, at least, is that the argument of the multiplicity of parts of the engines has comparatively little weight. The decrease in the size of parts, with the consequent increase in accessibility, in accuracy of adjustment, and in ease of repairs, is a natural sequence of the growth in the number of parts, and seems sufficient to overcome the disadvantages. It will be pointed out, further, that the increase in the number of working parts, due to the use of triple screws, is only apparent, as ordinarily there would be not more than eight cylinders employed on the triple-screw ships, against ten cylinders that would necessarily be used in the proposed five-cylinder quadruple expansion engines for the twin-screw ships of the United States Navy.

A much more serious objection to the use of triple screws than the multiplicity of engine parts is found in the greater intricacy of the piping plans and in the increased number of valves required. This objection is serious. Twin-screw warships are complicated enough at best. This disadvantage has been reduced somewhat, however, by several simple methods. The use of electrically operated auxiliaries has done much in this respect, especially as regards piping outside of the machinery space. Piping plans on American ships are very carefully studied, and are so designed and arranged as to reduce the number of valves to a minimum and to render plain to the engineer the leads of all pipes. All valves are marked plainly to show the connections. Many of them indicate as well the amount of opening of the valve. As a result of this care in the laying out and installation of piping and valves, mistakes in the operation of the valves are made almost impossible and undue intricacy of the piping plans is avoided. This absence of complexity is especially marked when comparison is made with some of the earlier twin-screw ships.

The growth in number of auxiliary engines owing to the employment of three main engines is another disadvantage of the triple screw system that is much more apparent than real. Ordinarily, there is no increase in the number of auxiliaries in use, only an increase in the number available for use; and, as a rule, these uneconomical auxiliaries are worked much more nearly at their rated capacity and are thus considerably less wasteful of steam. American experience has been that the auxiliary machinery gives most of the trouble on board ship, and American vessels have been more frequently disabled on account of the failure of these small engines than from any other cause due to the machinery. A larger reserve power in this, the weak part of the machinery, is too great an advantage not to be well worth its cost.

The increase in engine room force required with the three engines is not excessive, being twelve men at the most. This cannot be considered a disadvantage for warships. The added staff consists entirely of skilled mechanics, and these men are especially useful in making repairs while under way. The recent Spanish-American war experience tends to show the imperative necessity of some such mobile reserve for the

maintenance of a vessel, constantly under way, in a condition, at all times, of thorough efficiency. With this increase, there is always some one at hand to take the place of any man overcome by heat or sickness, and crippling of the crew as well as of the machinery is guarded against. I repeat that the increase in the engine room force necessitated by the adoption of three propelling engines cannot be counted a disadvantage in men-of-war, under war conditions. The formation of the stern post and rudder is made somewhat complicated by the use of the central propeller, but not more so than in any single-screw merchantman, and I apprehend that this disadvantage will not be given great weight by any designer.

To obtain a proper conception of the advantages of triple screw propulsion, it is necessary to consider, also, the latitude afforded by this system in the methods of running the ship under cruising conditions, since either one, two, or three screws may be used. There have been many trials of triple-screw ships under each of these methods of propulsion, and it may be interesting to give a few of the results which have not hitherto been published, so far as I am aware. Taking a vessel of, say, 12,000 tons, 23,000 horse-power, and 22 knots speed, when all engines are used at full power, it is found that:—

1. The power required to drag one screw, uncoupled from the engine and left to revolve freely, is 150 horse-power at 10 knots; 600 horse-power at 15 knots.

2. If coupled to the engine, at 10 knots speed, the power absorbed in dragging is slightly in excess of 300 horse-power.

3. If two screws are dragged the loss from drag is practically double what it would be with one idle screw for the same speed of the ship.

4. The loss in power due to condensation in an engine (not the result of expansion of steam in the cylinders, but attributable directly to the heating of the cylinder walls) is almost exactly one pound of steam for each horse-power of the maximum power for each engine. This figure is approximately correct for all speeds, increasing slightly for the lowest speeds. It applies to jacketed engines.

5. With three equal screws, the centre propeller has not sufficient area to give economical results when used alone at speeds above eight knots. With three equal screws, the use of the two wing propellers alone can be depended on to give a considerable gain in economy for all speeds from 8 to 17 knots, inclusive. These results have been gathered from fully authenticated trials, not only of American ships, but also of triple-screw ships in other navies.

All screws were practically equal in disc area in the trials from which these results are obtained. With these points known, the problem of the design of triple-screw ships is greatly simplified. The disadvantage of the drag of a screw is measured, and the advantage of the fitting hitherto adopted, which provided for the disconnecting of any idle screw from its engine is clearly developed. The necessity of giving sufficient disc area of propeller is, as was to be expected, prominently shown by the failure to secure economy with one engine in use, except at the very lowest speeds.

The value of economical engines is so universally recognised to-day that it seems almost unnecessary to mention it, but this value is, in a warship, far greater than the mere saving in the coal bill, though that is an important item. The matter of economy in the use of coal may make all the difference between victory and defeat. Coal endurance limits the radius of action of the ship and determines definitely the scope of her operations.

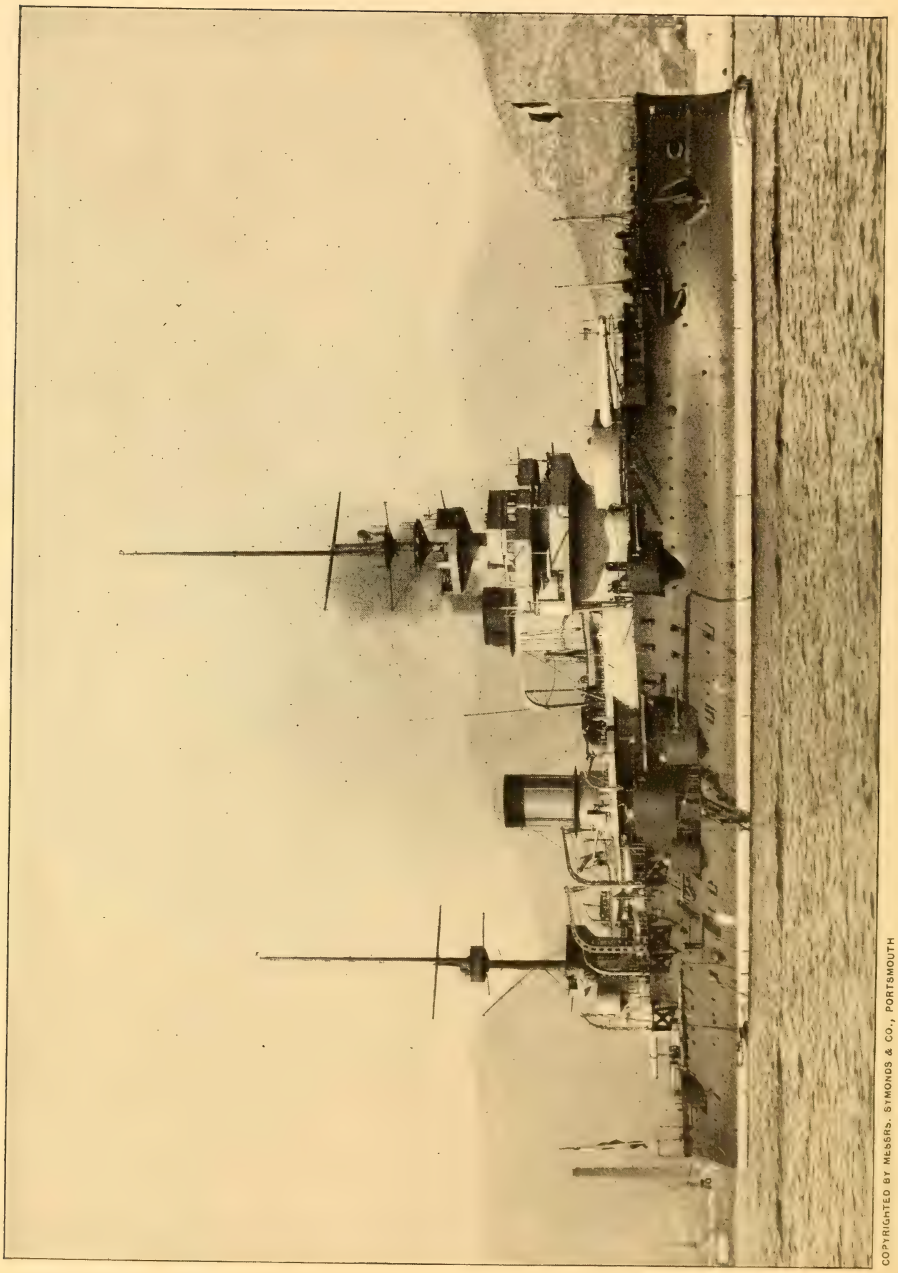
If three screws are to be fitted to a warship, and the design is to conform to the conditions of economical propulsion obtaining on these vessels, as shown by our present knowledge of the effects of three screws upon propulsive and engine efficiency, there appear to be but two practicable arrangements: — The central engine should be considerably more powerful than either of the wing engines, or it should be considerably less powerful. This follows from the

fact that a propeller design which will give in one screw sufficient area for the ordinary cruising speeds up to 12 knots is nearly impossible if the same screw is designed to be worked as one-third of the propelling system for the highest speed of the ship. The proportions of the screw must be changed to suit the latter conditions. It is evidently not wise to use as much as two-thirds of the full engine power for cruising at one-tenth power. The use of three equal engines is, therefore, out of the question as far as comparative economy goes. If a small centre engine be used, it would be practically an auxiliary. A very large screw necessarily being fitted to secure a fair propeller efficiency at low speeds, when the small engine alone would be used, it would be of practically no value at the highest speeds.

I consider, therefore, that it would be far better practice to use a large centre, and two small wing engines, in which design under no conditions would there be a useless engine. Of course, either of these plans involving the use of two different sizes of engines on the same ship is disadvantageous, but this disadvantage is not so great as a casual view of the conditions would seem to indicate. Engines do not break down in service. Careful designs for the maximum power insure good working of the machinery. Accidents to the engines are extremely rare, and are due almost invariably to some defect in a seemingly unimportant detail. The engine itself, so far as its large parts are concerned, does not break down, and a supply of the lighter spare parts provides for all emergencies such as are ordinarily met. On the other hand, it is well to note the many advantages due to the use of different engines. There is, in particular, much to be said in favour of the plan of installing small wing engines in a triple-screw ship. It is a fact that commanders of American ships hesitate, as naturally they should, to enter or leave a port with only one screw in use. They desire to retain the practical advantages of handiness accompanying the use of twin screws. It is, further, a fact that ships which ordinarily cruise at speeds of from 14 to 16 knots have been found to make better speeds, in time of war, than ships of the same class but of lower cruising speed. These conditions, combined with the proved efficiency of the use of the wing engines at speeds up to 17 or 18 knots, have been, with the United States, the determining factors in causing the adoption of designs involving the use of the smaller wing engines. It has been found advisable to fit economical machinery for cruising at speeds as high as 16 knots. While engines which will be most economical at this speed will not be the most desirable, in this respect, for a speed of ten knots, they will retain considerable advantage over any other system, in the reserve which will be ready for instant use.

The problem of the design of the propellers to give a proper efficiency for low speeds, and to be good also at the highest speed, offers, in this system, no difficulties. The reduction in the size of the wing engines below what would be necessary if three equal engines were used, effects a saving of about 200 horse-power, or its equivalent in steam, due to the decreased condensation on account of the smaller engines. This figure applies exactly to the recently designed American 22-knot armoured cruisers. The ship is economical at all the ordinary cruising speeds from 10 to 17 knots. The tactical advantages of working with twin screws are retained at all speeds, high or low. It has been pointed out that the decrease in size of screw is especially advantageous for the wing screws, and that it is advantageous, on account of the superior propulsive efficiency of the screw working in the following wake, to have a large power on the centre engine. These conditions are especially well fulfilled by the use of the smaller wing engines.

To reduce the engine room space it is advisable to place engines abreast in the ship. It is also a great advantage to arrange the engines in this way, as it makes possible the placing of a part of the boiler power abaft the engine, which gives easy solution to all problems connected with the change in trim due to the use of light water-tube boilers, and



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THE FRENCH TRIPLE-SCREW TURRET SHIP "BOUVET." LENGTH, 382 FEET. BREADTH, 70 FEET. DISPLACEMENT, 12,200 TONS. I. H. P., 13,000

also reduces vibration by placing the engines in the strongest part of the ship. In fact, the centre and most powerful engine is exactly at the point of greatest resistance of the hull to vibration. By using smaller wing engines it is also easier to arrange the engines abreast than it would be to install twin-screw engines of the same total power. This follows from the lozenge shape of the space available for the engine rooms beneath the sloping protective deck and above the rising bottom of the ship. Again, but one screw is dragged (revolving freely, uncoupled) with the two engines in use. This screw is a large one, it is true, but the drag is probably not so great as it would be with two smaller screws of the same total power.

It is, also, regarded as an advantage for this system that there is always one-half the full power available in case of accident. The centre engine is seldom used, and experience goes to show that it is always in a condition of very good efficiency. The customary employment of the smaller wing engines insures ease of making the regular repairs. It is but fair that I should state that, with its very large screw, designed for transmitting about half the total power at full speed, the use of the centre engine alone may prove slightly more economical than that of the wing screws for a speed of about ten knots, this superior efficiency following from the working of the screw in the following wake. I do not expect, however, that the centre engine will often be employed alone, as the manœuvring qualities and general handiness of the ship are so much improved by the use of two screws at all times. It should, however, be pointed out that the handiness will be retained at full power, and will not be affected badly by the reduction in the size of the wing engines.

In a word, the arrangement of triple-screw engines, with approximately one-half the total power placed upon the centre engine and approximately one-quarter on each of the wing engines,

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THE ITALIAN TORPEDO CRUISER "GOITO." ORIGINALLY EQUIPPED WITH THREE SCREWS. SUBSEQUENTLY THE MIDDLE PROPELLER WAS REMOVED, TOGETHER WITH ITS ENGINES, AND NOW THE "GOITO" IS RECORDED AS A TWIN-SCREW SHIP

seems to fit a warship and its conditions remarkably well.

Ramming and torpedoing would lose much of their danger with the small engines outboard. There is a certain prejudice among naval officers against any system that shows so plainly as do triple screws the enormous amount of power installed in the ship and so seldom employed. These officers would possibly prefer to imagine all the power in use, even when knowing,—as they all certainly do know,—that frequently not 10 per cent. of the total power is actually being developed. The loss from drag of an idle screw is plainly seen, but they forget the loss in the engine cylinders from condensation, which is often much greater. Not to employ ordinarily the reserve power plant increases the value of this reserve as well as the economy. It may appear unwise to install a plant that is so seldom used, yet when the power is wanted, it will be wanted badly, and at such times every pound of coal in the bunkers may be worth a ton at ordinary times.

The use of two screws with two engines upon each shaft has not been considered as an alternative to the use of triple screws. This arrangement, with its four engines, has nearly all of the disadvantages attendant upon the use of three screws, with very few of their advantages. Further, it presents the grave tactical disadvantage which was developed so fully in the cases of the United States cruisers *Brooklyn* and *New York* at Santiago last year. These vessels were fitted with four engines working twin screws, the forward engines being ordinarily uncoupled. This system was designed to insure economical running at low speeds, but it was impossible to couple up the forward engines without stopping the ship. During the battle of Santiago, stopping the ship for the fifteen minutes necessary to couple up the engines would have been fatal. On the contrary, in the case of the *Minneapolis* the centre screw was coupled up while the two wing screws were driving the vessel at a speed of 17 knots. It is a great advantage that full power can always be applied on a triple-screw ship without stopping. Such conditions would surely have been very valuable to the *New York* at Santiago.

It may naturally be inquired why the superior efficiency due to the use of triple screws has not led to their general adoption in the merchant marine. Triple screws undoubtedly would have been used in that service if the conditions obtaining were the same as those existing in the navy. Merchant vessels, however, instead of running at a variable speed, are always worked at their full power, and there would be consequently no advantage to their owners in fitting machinery capable of working economically at low speeds. The stroke of engines in these vessels is, also, not limited by a protective deck, and it is always possible with them to obtain the great piston speed necessary for economy by increasing the height of the engine. We see, therefore, that two of the main reasons for the use of triple screws in men-of-war do not obtain in the merchant service. Added to this must be the fact that the cost of building and installing three engines when not all of the same size, is considerably greater than that of two engines of the same total power, and also that the cost of maintenance due to the larger force required would be considerably increased. From these considerations, it would appear that triple screws may not be desirable for the merchant service under present conditions of size and speed. I think, however, that any trans-Atlantic line which would definitely adopt the triple system would be patronised by a considerable number of persons because of the greater security afforded by its use.

The statements as to the desirability of using three screws on war vessels, and the fact that they are being used to so great an extent in the continental navies, will naturally lead the thoughtful student to wonder why they have not been adopted, to some extent at least, in British vessels. This feeling will be the stronger from the fact that British engineers are justly considered to be thoroughly progressive and abreast of the times with respect to every feature that

would tend to an increase in the efficiency of vessels.

It has occurred to me that whatever other reasons may have caused this non-use until now of triple screws on British vessels, one feature of the case, at least, may serve as a partial explanation. I am led to this belief all the more from the fact that it agrees with the experience of all designers with respect to some forms of marine machinery, which, while apparently very peculiar, are the best adapted to the particular cases where they have to be used, viz., the exceedingly light-draught steamers required for certain river service.

Yacht designers are very familiar with the fact that vessels designed for general cruising on the British coast are very different from those for general use on the coast of the United States, due to the fact that in the case of Great Britain there is everywhere an ample depth of water, while in that of the United States the reverse is true.

In just the same way the United States are restricted in the draught of their war vessels to about twenty-four feet, while the large British ships can, and do, in some cases, draw about twenty-seven feet. As a consequence of this radical difference in the circumstances under which large powers have to be applied, the problem of the number of propellers is presented to the designers on the two sides under a different aspect, and I am inclined to believe that this has had a great deal to do with the fact that British designers have not thus far paid much attention to three screws. Had they been compelled to face the problem of putting large powers in light-draught hulls, I think they would have been driven to a consideration of the advantages of three screws, and probably would have taken hold of the matter with their characteristic energy.

Let me add, in conclusion, that I have given this subject of triple screws very careful study, and I believe that for war vessels their use is thoroughly logical. Further than that, I believe that although contrary to the general accepted idea of duplication of parts as far as possible, the plan which I have suggested for dividing the power between one large central engine, to develop about half the power, and two smaller wing engines, each of about one-quarter power, will give the best results, and is likely to be the system that will finally obtain general adoption.

THE CASE OF TRIPLE SREWS

THEIR ADVANTAGES

Smaller engine parts.
Greater ease of overhauling.
Greater accuracy of adjustment.
Lack of vibration.
Subdivision of power.
Increased (probable) available power.
Increased ease of protection.
Increased handiness when partly disabled.
Smaller water-tight compartments.
Smaller propellers.
More efficient propellers.
Less peripheral speed of propellers.
Less screw friction.
Increased revolutions of engines.
Decreased loss from cavitation, the word being used in its broadest sense.
Increased efficiency of the screw working in the following wake.
Decreased danger to propellers in ramming.
Decreased danger to ship that is rammed or torpedoed.
Shorter propeller shafting.
Decreased racing of screws.
Freer design of stream lines.
Freer access of water to screws.
Increased piston speed and economy.
Decreased total size of cylinders.
Decreased weight of machinery.
Decreased condensation in engines at all,—especially at low,—powers.
Adaptability to light draught.
High ratio between stroke and diameter of cylinders.
Less glacis plating required.
Ease of propeller design.
Latitude of engine design.
Great gain in economy at low powers.

THEIR DISADVANTAGES

Greater number of parts.
Greater number of valves and pipes.
Greater number of auxiliaries.
Increased engine room force.

Loss of power due to drag of idle screw.

With centre engines alone used, the loss of the tactical advantages due to twin screws.

THE CASE OF THE PROPOSED SYSTEM OF TRIPLE SCREWS WITH SMALL WING ENGINES

ADVANTAGES

It fits the ship.

Ease of installation and design.

Great gain in economy at all speeds.

The tactical advantages of twin screws economically retained.

Engine room space is reduced.

The powerful centre engine has a most economical screw working in following wake.

The vibration is minimised.

The loss from drag of screw is minimised, one screw only being dragged.

Small size of working parts.

Two independent plants each capable of economical propulsion up to 15 knots speed.

Small size of working parts with maximum ease of repairs.

DISADVANTAGES

Two sizes engines in same ship.

Increased cost of building.

Increased number of spare parts necessarily carried.

The disadvantages are few, and, from a broad standpoint of military excellence, they are unimportant. The advantages are many, including better design and installation, greater ease of maintenance, and greater efficiency at all speeds. I consider this the logical arrangement of motive power on high-powered warships.

COMPARATIVE ADVANTAGES OF ELECTRICITY, STEAM, AND COMPRESSED AIR FOR MINING PURPOSES

By William Edward Garforth, M. Inst. C. E.

THE question of mechanical power for underground requirements connected with haulage, coal-cutting and pumping is at the present time perhaps more than any other subject, occupying the attention of mining men. High-pressure dry steam is the most economical power for use on the surface. Electricity is the most economical and convenient for transmission of power. Compressed air is the safest underground. A combination of the foregoing will probably give the best results.

In a paper recently read before the Engineering Conference of the Institution of Civil Engineers, of Great Britain, the author stated that whilst high-pressure dry steam is the most economical when generated on the surface in boilers of modern type, and supplied within a limited distance from the winding, pumping, dynamo, hauling, and other engines, yet this does not apply when the boilers and engines are placed underground. The expense of maintaining boiler flues, the danger of setting fire to the surrounding strata, the difficulty of dealing with the exhaust steam, and of obtaining suitable feed water, etc., makes this system unsuitable for use in the pit. Besides, there is also a serious interference in maintaining strict discipline amongst the workmen, and since the introduction in Great Britain of the Compensation Act insurance companies have refused to undertake extra risks without increased premiums. These objections, amongst others, will in future prevent the erection of boilers underground.

Many instances can be given of the successful working of underground haul-

age by engines placed on the surface and ropes carried down the shaft and for long distances into the workings. Provided local conditions are suitable, and proper attention has been given to the drums, pulleys (of large diameter), ropes, and accessories, this system of haulage is probably the most economical that can be adopted, besides giving, as regards fire-damp, the additional advantage of safety.

The statement that compressed air is the safest power conveys to those in charge of coal mines, which naturally and sometimes suddenly give off large quantities of fire-damp, an impression of advantages which compensates to a great extent for the loss of economy. The latter can be ascertained, but it is almost impossible to estimate the loss sustained by the stoppage for some months of a large colliery consequent on an explosion. Even the most modern compressed-air plant, designed either on the wet or dry principle, single or double-stage compression, water-jacketed, driven by engines and boilers of the most modern type, pipes of large diameter, numerous air receivers, etc., show that the losses by heating, leakage, etc., are such that, from an economical point of view, compressed air cannot compare with electricity.

Before referring to the advantages to be gained by the use of electricity, it may be pointed out that there are in a coal mine sufficient natural dangers without introducing artificial ones. As an instance of this, several collieries formerly forced artificial gas from the surface down the pit to light the roads near the bottom of the shaft, and where the traffic was greatest. So long as everything connected with the underground workings appeared satisfactory, no complaint was entertained, but when an explosion occurred it was suggested that the cause of the accident was an accumulation of artificial gas above the roadway timbers, due to leakage from the pipes. In the same way electricity is, by some engineers, being recommended for use at the coal-face in all mines on account of its greater economy as compared with compressed air. The danger connected therewith may not be fully realised in the case of certain deep mines until an accident takes place, attended with serious loss of life. Then—judging by other accidents, economy is forgotten in regretting the loss of life, and afterwards in considering the claims made by the relatives of the men who have been killed or injured. At the same time, there are many mines in which it will be perfectly safe to use electricity, provided the cables, motors, and accessories combine the latest improvements.

Not only can high efficiency be obtained by the use of electricity, but both generating and transmitting machines are exceedingly compact and require only a limited area, the cables are easily and quickly laid, occupy small space, and, being flexible, are not affected by the lifting floors of the mine.

The cables do not require rigidly fastening underground; it is, in fact, preferable to suspend them by means of a cord from the props supporting the roof, so that in case of a fall of stone, etc., the suspension breaks readily, allowing the cable to drop, thus saving it from injury.

With regard to the two systems,—polyphase and continuous currents,—each has its advantages and drawbacks.

The chief points of the three-phase current system are:—

1. Absence of commutators in both generators and motors, with consequent saving in wear, reduction of repairs and renewals, and less need of constant skilled attendance.

2. Complete immunity from sparking.

3. No starting resistance required for motors up to 10 brake horse-power, unless exceptionally large starting torque is required.

4. High pressure can be transmitted without risk to generator or motor, and copper is saved in the line.

With respect to the continuous-current system, the following may be mentioned:—

1. A single pair of conductors is required as against three conductors.

2. Greater starting torque can be obtained with the motors.

3. Accurate measurements can be more readily taken.

From a pitwork point of view the complete absence of sparking at the motor would at first sight seem a consideration in favour of the three-phase current. The best continuous-current motors for this work are, however, now usually boxed in and for all practical purposes are gastight. Thus the danger attending the underground use of electric motors fitted with the latest improvements is reduced to a minimum. At the same time, before adopting electricity, every possible danger should be considered and guarded against, especially in the line of cables. A fall of roof, or other accident may at any moment produce a short circuit, or sever the cable and result in serious sparking.

The greatest care should consequently be bestowed on this portion of the electrical installation and the system involving the simplest arrangement and least number of cables should be preferred. The safety of a mine is equal only to the most unsafe lamps or appliance used in it in the same way that the strength of a chain is only equal to that of the weakest link.

With regard to the best form of cable for continuous-current in mining work, concentric conductors seem to be the simplest and safest.

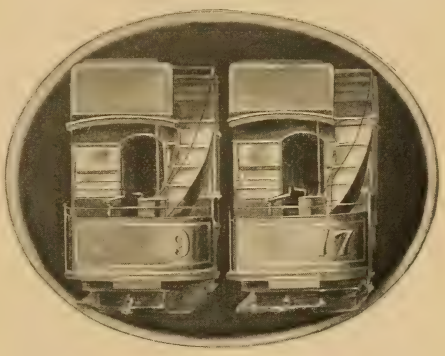
The adoption of an earthed circuit is open to many objections. Safety is the predominant factor in planning all underground work, and a tight system is on this account to be preferred. Security from shocks is claimed for the earthed system, but in practice this has not always been found to be the case.

For the cable which requires to be vertically suspended down the shaft, vulcanised rubber is the best class of dielectric. The very best qualities of rubber, such as are used for high-class underground street mains, are too soft for this, and a good insulating rubber containing more pigment and of increased thickness should be employed. The core should be lapped with tape and compounded and sheathed with galvanised iron wires of about No. 16 S. W. G. compounded, and coated with compounded jute. Lead-covered cables should not be used for pit work. All cables should be sheathed.

As a prime source, steam, when used under the conditions previously described, possesses the greatest advantages. For the transmission of power to a distance, electricity is the most economical, efficient, and handiest. In the presence, or with the possible occurrence of gas, compressed air is the only one which can be absolutely relied upon. For the distribution of power to distant parts of the mine the writer has on many occasions suggested and advocated the employment of a combination of the foregoing, *i. e.*, generating the electricity on the surface, and by a cable down the shaft and along the main roads, conveying the same to an electric motor coupled by gearing or ropes to an air compressor fixed in a well-ventilated position at a safe distance from the coal-face; then through pipes of suitable diameters conveying the compressed air to pumps, hauling engines, or coal cutters, as desired. As the coal-face advances, the motor and compressors are moved. By this arrangement the surface engine-house and foundations are saved, and the motor, can, with a little extra work, be fixed in a disused road. By a careful consideration of the circumstances and requirements, this combination of the best characteristics of each system should overcome all objections to the low efficiency of compressed air and the danger of electricity, and lead to a consummation of an economical and safe system for the distribution of power underground.

Current Topics

THE White Star Line steamer *Oceanic* has been the all-absorbing marine engineering topic of the month, and comparative tonnage and horse-power figures and speeds have been glibly used even by the average man met in the streets. On the multitude, however, they have more than likely failed to make a correct impression of their meaning, and a realisation of what the 28,000 horse-power of the big ship actually represent has come to only a few. Taking into account the steam used by the host of auxiliary engines and pumps on board of such a vessel, and that used for heating purposes, it is probably not far out of the way to make a total allowance of 18 pounds of steam per hour for each horse-power of the main engines. This would mean that 252 tons of steam per hour would be necessary to keep things going, and that, therefore, the same number of tons of water would have to be evaporated in the boilers during the same time. For a 24-hour run the amount of steam consumed would be a little over 6000 tons, and on the liberal basis of a boiler performance of 10 pounds of water evaporated for every pound of coal burned, this would mean a daily coal consumption of at least 600 tons. It is expected of the *Oceanic* that she will preserve a clock-like regularity in her trips, be the weather calm or boisterous, and as one Wednesday will witness her departure from one side of the Atlantic, so the following Wednesday morning should see her arrival on the opposite side. To accomplish this in fair weather would require less power than the ship has; the balance is to be a reserve, available should occasion require it. For this reason the daily consumption of coal will probably range below the estimated figure given above. To show how the *Oceanic* transcends



CROSS-SECTION OF ONE OF THE "OCEANIC'S" TWO FUNNELS SHOWING THAT TWO FULL-SIZED TRAMWAY CARS CAN PASS THROUGH IT SIDE BY SIDE

that leviathan of earlier years, the *Great Eastern*, it is interesting to recall that the length of the latter was 680 feet; that of the *Oceanic* is 704 feet. The former's light draught was 15 feet; the latter's is 22 feet. Their respective light displacements are about 12,000

tons and 18,000 tons, and weights of hull, 8000 tons and 12,500 tons, and when voyaging, it is estimated that the *Oceanic* weighs about 28,000 tons, against the *Great Eastern's* 25,000 tons. It had become customary in later years to look upon the *Great Eastern* as a monument of extravagance as regards size, and as physically and financially beyond proper control; and yet in the *Oceanic* the world has a vessel whose figures altogether overshadow those others and whose success is practically assured. But the first was an adventure on theory, while the second represents enterprise boldly advancing on experience.

STEAM boilers are so apt to be considered as vessels for withstanding only internal pressure that the possible existence of a vacuum in them, under certain conditions, is easily overlooked. An account of an unfortunate accident which was recently given in the *Shipping Gazette* illustrated this and its dangers. The boilers of the British steamship *Elderslie*, while at Smyrna, some months ago, having been blown down, the third engineer, E. Marshall, proceeded to open up, assisted by a Greek fireman. The boilers were two in number, double-ended, and apparently of the ordinary return-tube type. The manhole door, which was being removed at the time of the accident, was 16¼ inches by 12¼ inches, and was in the end plate at the after end of the boiler. According to the testimony of the Greek fireman, Spinoli, one dog or cross-bar had been taken off the door and the other nut started, when Marshall sent him to prepare to take off the door of the manhole of the other boiler. The fireman had only just left when he heard a loud report, and, going back, he found the manhole door open, but could see nothing of the third engineer, nor of the manhole door. The chief engineer, who was on deck at the time, then joined in the search for Marshall. He says the boiler was so hot that he could not keep his hand in it, and on trying to put his head through the manhole, found it impossible to do so on account of the heat. He at first thought that the third engineer had allowed the door to drop into the boiler, and in attempting to get it out had gone inside and had been overcome by the heat. He then tried to look in with lamps, but could see nothing until he got the forward bottom doors off, when he discovered blood on the sides of the furnace.

THE boiler was then allowed to cool down for about four hours, after which it was possible to get inside. The dead body of the third engineer was then found lying on two of the longitudinal stays close to the forward end plate and opposite the manhole. The skull was fractured, and there were evidences of scalding. It would thus appear that the man was drawn into the boiler and carried from end to end, a distance of 16 feet, and was thrown against the opposite end plates with sufficient force to fracture his skull. Moreover, the arms and shoulders looked as if they were seriously injured, and the clothing was torn in places. The body was discovered on a level with the place where it was drawn in, evidently having slid along the longitudinal stays. The manhole door was found resting on the tubes at the same end, and almost immediately below the body, it also having been carried nearly the length of the boiler, but being small enough, it fell between the stays. A spanner was also found on the top of the combustion chamber which of course was in the middle length of the boiler, as the latter was double-ended. The only explanation of this remarkable accident appears to be the one given by the Board of Trade circular. When the boilers were blown down neither the safety-valves nor cocks were opened, although the chief engineer gave instructions that they should be. The boiler was evidently blown down at a fairly high pressure, and when the steam condensed there would be a loss of pressure inside, so that the tension there would be considerably less than the atmospheric pressure outside. Marshall

was working on a platform level with the door. When the latter was removed the rush of air carried him in, dashing him to the other end of the boiler in the manner described.

It is through the steady growth of machinery employment and the reduction of manual labour to a minimum that some of the most telling economies in iron and steel works, in engineering shops, and in mining operations have, in recent years, been effected, and in this respect European and American enterprise have profited to most remarkable degrees and have supplied experience which now is being taken at its proper worth in Great Britain as well. At a meeting a short time ago of the Staffordshire Institute of Iron and Steel Managers, the president, Mr. H. Le Neve Foster, urged the importance of following the American practice of adopting mechanical methods to the fullest possible extent, and stated as a sample of what is already being done in this direction that pig-iron casting machines are now being employed at some of the north of England blast furnaces with a saving of something like 2d. per ton, and that pig breaking machines have been put into service with equally successful results. A saving of 2d. per ton on the pig iron produced throughout Great Britain last year would mean an economy of £70,000. At Messrs. Bolckow, Vaughan & Co.'s works, tipping gear, which had been erected in the steel blooming mills, had reduced the cost of labour from 1s. 2d. down to 2d. per ton on an output in one mill of 500 or 600 tons per turn of twelve hours. Thus the capital outlay was quickly paid over and over again. In illustration of the importance of further mechanical applications to the mining and quarrying industries, it was mentioned that a reduction of only 1d. per ton in the cost of limestone quarried last year would have represented a saving of £50,000, and a similar reduction on the cost of the coal raised in the country would have meant a saving of over £100,000. Belgians and Germans have been quite as keenly alive as Americans to the importance of economies such as these in their own domains, and have accordingly helped to set a pace which the British works proprietor and manager must follow so as to ward off that destructive foreign competition of which so much has been said and written for several years past.

Added to the relatively slow awakening to the importance of labour-saving methods as means to retain industrial supremacy, Great Britain suffers to-day perhaps more than any other country from what have been aptly termed the "holiday" bacillus and the "strike" microbe. Indeed, Great Britain seems to be particularly the land of strikes and holidays, and between the two the manufacturer has a hard time. In discussing this feature of British industrial conditions recently in *The Iron Age*, Willard S. Mattox, writing from Newcastle, indulged in the following bit of suggestive work in subtraction. Let us, he said, begin with 365 days in the year. This number is common to the chronology of all civilised nations, so that Germany, America and Belgium have no advantage at the start. From this we must subtract, roughly, say 52 Sundays. This is a non-working day for all countries alike, and still leaves the three commercial competitors on an even footing of 313 days. Here is the point of departure, one of them, at least in so far as the comparison includes the United States. The British manufacturer must allow for about 14 days when his men won't work, at Christmas and New Year. Then he must subtract about 10 days at Easter, when his shops must close down. For all practical purposes, every Saturday in the year may as well be excluded from the working list, because many engineering works and manufacturing plants generally give the men a half day on Saturdays, and the concrete results of the first half day's work cannot be much. But to be absolutely impartial

let us deduct only 52 half days, or 26 working days. Then include bank holidays, and in each district a number of local celebrations, which are only locally recognised, and the master can count on about 250 days in the year when he may expect to turn out his products and make money. This problem in subtraction cannot deal with workmen's eccentricities. It goes only so far as the figures allow. But human perversity in the form of workmen's whims will lessen the total by several days more. By way of variety, just because he does not get enough holidays, a strike is thrown in for good measure, and the manufacturer's capital is further reduced toward the vanishing point. All this is digestible food for reflection.

A GOOD story, which comes from one of the western mining towns in the United States, even if it be nothing but a story, illustrates anew that things are not always what they seem. Several months ago, so runs the tale, a company in the town in question bought a carload of crushed ore in Mexico. Advices were duly and officially received that the ore had been shipped,—twenty tons of it. Weeks slipped away and the ore did not come. The smelting company politely asked the local agent of the railroad company when it would arrive. The local agent said he had never heard of it. The smelting company then appealed to the general agent. From him the question passed along the line until it reached a potent official, who started out a tracer for the carload of ore. A tracer is a document on which every agent, train conductor, and other person who has had anything to do with a shipment must say whence he took it and where he laid it down. From the mine in Mexico the carload of ore was traced from junction point to junction point, from station to station, until it was well within the railroad company's local yards, and thence to a side track by a roundhouse and into the possession of the master mechanic. The carload of crushed gold ore looked like a lot of coarse yellow sand, and had been knocked about and disrespected, as a carload of common sand should be. When the officials were notified that the car had been traced to the master mechanic's track they sent him a note asking him of the disposition of the car, giving its number. The master mechanic turned the note over and indorsed on the back:—"The car contained a d—— bad quality of sand. Some of it I used in the sand boxes of the engines, but it was not serviceable, so I had it scattered along the right of way." The railroad company paid the smelter company $180 a ton for the sand.

HENRY CLAY FRICK

A BIOGRAPHICAL SKETCH

LIKE many who have attained conspicuous places in the commercial and professional life of America, Henry Clay Frick, of Pittsburgh, manufacturer of coke and steel, whose masterful business acumen has largely contributed to place Western Pennsylvania in the position of first importance in manufacturing in the United States, was reared in the wholesome environment of the country. His early education was the best that the schools of the vicinity afforded, but with a precocious bent toward business affairs, he gave up part of his school days, to gratify a desire for practical training, to the work of a clerk in a dry goods store.

In 1869, at the age of twenty, he

sought a permanent business occupation, but taking that which was offered, entered the office of his grandfather as bookkeeper, at Broadford, Fayette County, Pa. While in this place young Frick had his attention called to the value of the coking-coal deposits in that vicinity. Cokemaking, then in its infancy as an industry, was a business with which he was not familiar, but he made a thorough investigation of it, and entered into a partnership with a number of men in the locality, bought a tract of coal land, and built about fifty ovens for the manufacture of coke. This was his first business venture, and he undertook its management with much enthusiasm. The business expanded rapidly, as a ready sale for the product was found at the foundries and furnaces operating all over the country. The capacity of the plant was enlarged as the demand for coke increased, and in 1873 the firm had two hundred ovens. The panic of that year embarrassed many of the customers, and the sale of coke was curtailed considerably. Some of Mr. Frick's partners fell into financial straits, and the enterprise received a setback. In this emergency he appealed to several friends who had faith in his ability, securing from them the means to enable him to purchase the interests of his partners, obtaining control of the business.

Coal lands ranged low in price at that time and until the country recovered from the prostration of 1873. Mr. Frick took advantage of the depression and acquired several good properties which had been put on the market. When business revived, his superior judgment in these purchases was demonstrated by the fact that for a time the annual profits more than equalled the purchase price. In 1878 he sold an interest in his business to E. M. Ferguson, of Pittsburgh, and afterwards Walton Ferguson was admitted to the firm of H. C. Frick & Co. In 1882 the firm was merged into the H. C. Frick Coke Company, and Carnegie Brothers & Co., Limited, were large purchasers of the stock. The company is now the largest coke producer in the world, owning in the Pennsylvania Connellsville coke region, in Fayette and Westmoreland counties, nearly 40,000 acres of coal and 12,000 coke ovens, with a daily capacity of about twenty-five thousand tons of coke, employing upward of eleven thousand miners and coke operatives, and furnishing an enormous traffic for the railroads running into the iron-producing districts.

The association of Andrew Carnegie with Mr. Frick gave him a clear insight into the rare sagacity, executive ability, and commercial intuition of the latter. After the death of Thomas M. Carnegie, the junior member of the concern, on October 19, 1886, Andrew Carnegie sought not only for a successor to his brother, but for some one with the skill and executive ability to assume the entire control of the allied concerns with which Mr. Carnegie was identified, thus relieving him of personal responsibility and direction. Mr. Frick answered these demands in a superlative degree, and in 1889 he was admitted to the firm of Carnegie Brothers & Co., Limited, as its chairman, and continued as chairman of that association and its successor, the Carnegie Steel Company, Limited, since the reorganisation in 1892. In 1895, at the request of Mr. Frick, the duties of the chairman were divided, most of the executive details being transferred to the newly created office of president, Mr. Frick retaining the official title of chairman of the board of managers.

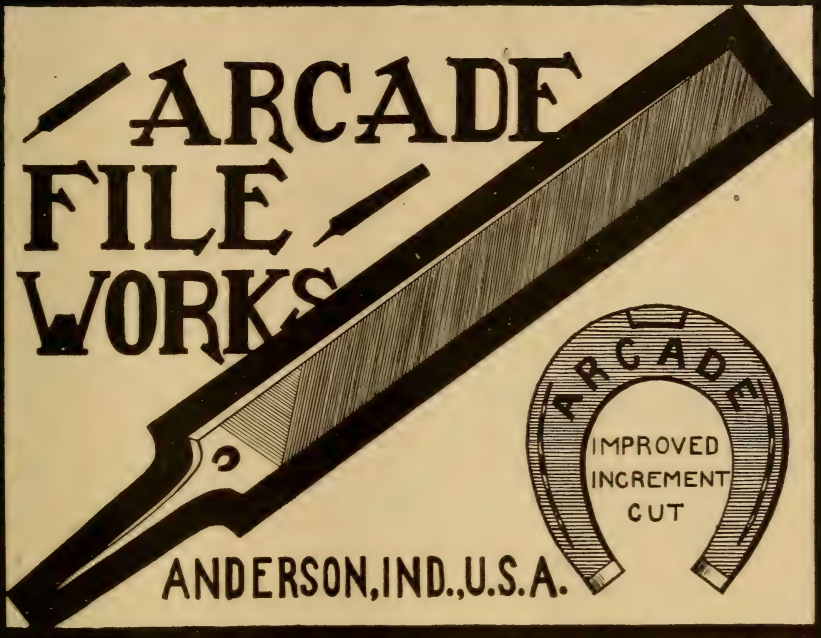
In 1897 he also relinquished the management of the minor affairs of the H. C. Frick Coke Company, becoming chairman of its board of directors, enabling him to give more time to his large and varied interests apart from the coke and steel business, and to gain some of the leisure which a life of incessant activity previously precluded. By reason of his position for years as the head of several large employing interests, Mr. Frick has necessarily been brought into public prominence occasionally through the labour disturbances incident to the operation of such great industrial enterprises, notably during the disturbance at the Homestead Works of the Carnegie Steel Company,

Limited, in 1892. Because of additions to the mills and the introduction of improved machinery, designed to lighten labour and at the same time increase the product, a number of men in many departments who received certain fixed rates per ton of product, known as "tonnage men," were enabled to earn wages in some cases 100 per cent. higher than was contemplated by themselves or the company when the wage scale was made three years previously,—wages unreasonably high, entirely out of proportion when compared with those of other men in the same mill, and very much in excess of the wages paid for similar work by the competitors of the company.

In the negotiations between the officials of the company and the officials of the labour organisations for a new wage scale, to take effect at the expiration of the then existing one, the labour officials refused to make or permit any reduction to be made in the rates paid to these "tonnage men." Mr. Frick took a firm stand for the correction of this manifest injustice, prepared a scale eliminating all the inequalities of the old one, and presented it to the workmen without the approval of the labour officials. A strike, involving all the men employed at the mill, ensued, attended with extreme disorder and rioting. Time demonstrated the wisdom and justice of Mr. Frick's stand in the matter. With less than a year's trial of the new scale, the workmen and others intimately connected with the trouble freely admitted its fairness and liberality, and that the strike was a mistake and wholly unjustifiable. After trying every means and exhausting every possible resource, including arbitration of differences by disinterested persons, and failing to insure the operation of the works through the agency of labour organisations, against interruptions on account of labour disputes, he finally discontinued contract arrangements with the employes through organisations, contracting instead with the workmen direct. As a result of this policy, suspensions of operations have become infrequent, the causes of discord minimised, and the condition of the workmen immeasurably improved.

In business Mr. Frick is wonderfully quick of comprehension, and accurate in his judgment of men and affairs. It appears easy for him to select the best man for a particular duty. He never lacks courage to vigorously carry out his decisions. He is equally firm and courageous in opposing any measure of which his judgment or strong sense of right disapproves. Personally, Mr. Frick is extremely modest and unassuming in his intercourse with others. His charities are great, but are quietly and modestly bestowed.

ARCADE FILE WORKS



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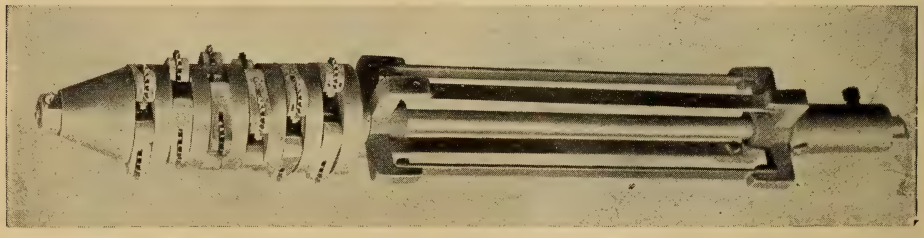
THE EFFICIENCY OF BOILERS; RESTORING, INCREASING AND MAKING THE SAME CONTINUOUS.

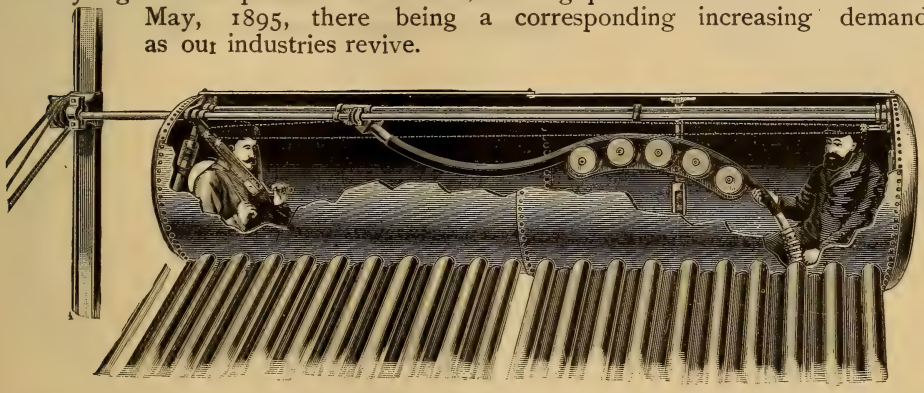
PRIOR to three years ago there was no method by which it was possible to entirely remove dense scale from the water tubes of boilers, hence the welcome accorded a tool designed on scientific principles that would make the work relatively easy and in the highest degree effective. The sheer folly of attempting to do by hand, work that taxes the capacity of a from five to ten horse power engine is now recognized and admitted by the more progressive of our steam users. They have discarded the use of mysteries such as alleged purifiers and compounds and such toys as alleged scrapers, rammers, scaling machines, etc., and realize the fact that a matter heretofore receiving but slight personal attention owing to their being busy with matters supposed to be of greater importance has resulted through ignorance, incapacity, or willfulness, or worse, a constant and ever increasing loss in the efficiency of boilers, necessitating where entirely unnecessary, additional boiler capacity and resulting in a loss in fuel to an extent that is almost incredible; there being no plant of any size in the country where the loss going on in the boiler room would more than meet the whole executive expenses of the concern.



CLEANING HEAD

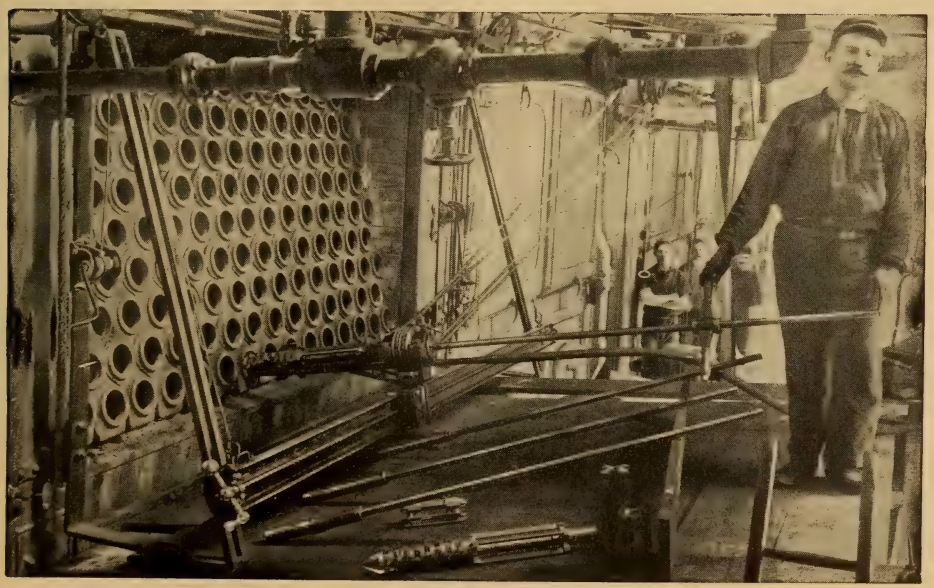
The cleaning head which accomplishes this drastic work as shown in the above cut is composed of a shaft about twenty-four inches long built up of discs —six to eight in number—depending on the size of the tube, with a 1¾ inches taper; to each of these discs is loosely pivoted three arms; to each of these arms is loosely pivoted a cutter wheel, 24 inches in all; the details being made of the best tool steel carefully tempered by expert toolmakers. This cleaning head revolves at from 1500 to 2000 revolutions per minute, depending on the size of the tube to be cleaned; the smaller the tube the greater the speed in order to get the impact, the force of which removes to a great extent the incrustation on the outside of the tube; the result is a sand blast effect. It is a rolling, hence disintegrating, action, not a cutting one and therefore will not injure the iron nor expand a thin tube but will take out all the foreign substances including the mill-scale, leaving the tube as bright as a gun-barrel; being the acme of perfection in boiler cleaning, hence the greater efficiency in a new boiler having its tubes polished over that of another new boiler having the mill-scale present; it being the opinion of experts that the loss in circulation due to the mill-scale alone is from nine to thirteen per cent. The burnishing of the tubes greatly increases the radiation and circulation and one particular case is reported where after thirty months service on using a wire brush the tubes were found as smooth as the day they were cleaned. This emphasizes the fact that the boiler-scale will not collect so

rapidly nor adhere so tenaciously in a burnished tube as it does where the mill-scale is present. Intending purchasers having tried the best known methods up to date have made tests before and after cleaning with this device with the result of the increased efficiency over the best they could do 19.49 per cent. in one case, 34.6 per cent. in another, 54.8 per cent. in another, and a saving in fuel in another case of 24.8 per cent. and this on scale only ⅛ of an inch thick. This seems almost incredible but these tests were made of their own volition by corporations who where determined that the apparently good results be confirmed by actual practice before they would purchase the device. The value of this device is accentuated by the fact of its rapid adoption during the period of this country's greatest depression in business; it being put on the market the first of May, 1895, there being a corresponding increasing demand as our industries revive.



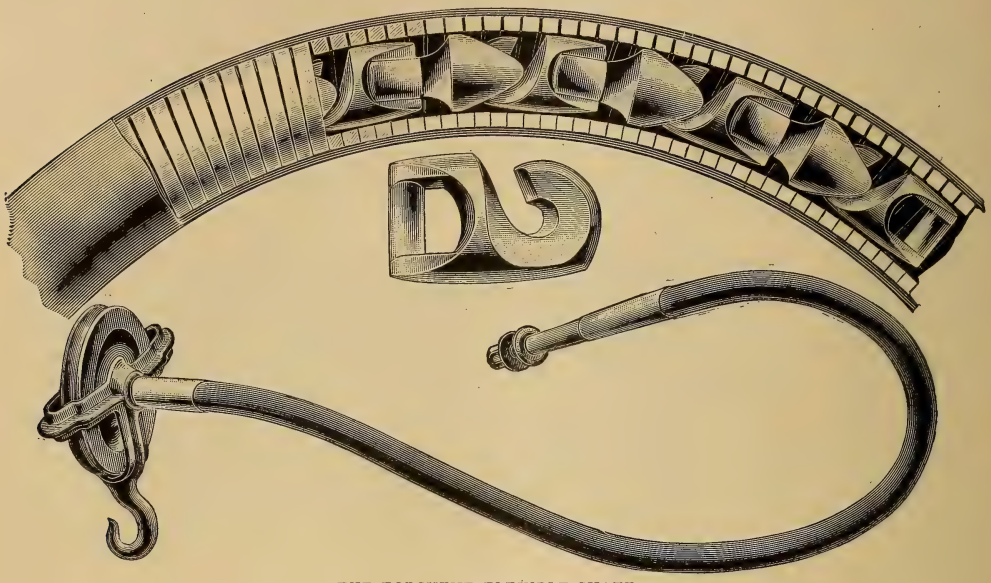
CLEANING A STIRLING BOILER

The above cut shows the device in operation for cleaning the Stirling type of boiler which necessitates the use of a flexible cleaning head and a flexible shaft of a new design having great power and lasting qualities; the whole being arranged inside of the drum of the boiler. For Climax and Hazelton boilers the feed gear is set vertically inside the drum; for Cahall and Cook boilers the feed is from the outside; for Munroe boilers the feed is set outside and horizontally;



for economisers, condensers for ice machines and other pipes or tubes used in industrial enterprises special appliances for meeting each case are provided.

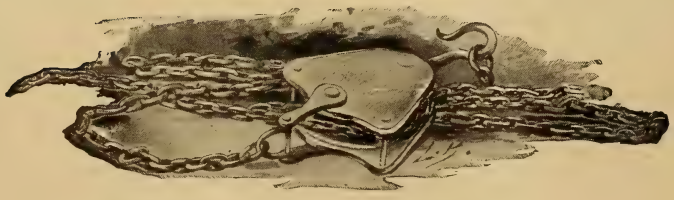
The above cut represents the Forsythe Flexible Shaft, the cone of which is made of phosphor bronze for high speed and steel for slow speed, which is en-



THE FORSYTHE FLEXIBLE SHAFT

cased in square steel wire made and tempered for this specific purpose. This shaft is made in any required length of section up to eight feet and the parts being interchangeable the sections can be coupled together to make a shaft of any desired length. It is a shaft requiring practically no repairs as a broken link is quickly replaced and combines marvelous strength with phenomenal durability under great stress.

All the above devices are manufactured by the Union Boiler Tube Cleaner Company, 230 Penn Ave., Pittsburgh, Pa., U. S. A.



AN INTERESTING ELECTRICAL PLANT AT NIAGARA FALLS

AN INTERESTING NIAGARA PLANT

THERE are many interesting electrical installations at Niagara Falls in the plants of the great manufactories that have been located there by reason of the cheapness of electrical power derived from the generating station of the world famous Niagara Falls Electric Plant. Of all these installations, that of the Union Carbide Company is most important in volume of electric energy consumed in its manufacturing processes. When the facilities of these works are fully developed, there will be in practically constant use not far from 25,000 electrical horse power, the entire output of five of the great generators in the central station of the Niagara Falls Power Co. Such an enormous consumption of power has led to radical departures from standards heretofore maintaining for electrical apparatus of the character called for in this work. To meet the requirement of this service most efficiently and with the least likelihood of interruption of service, very large units were called for. The design of these units has taken the engineers of electrical manufacturing companies into new realms, with the result that the eyes of the engineering world are centered on the apparatus that has been installed to meet the requirements here arising. It has, therefore, proven a matter of great surprise, as well as keen interest that contracts for this installation should have been awarded a company not heretofore favored with any of the great orders that have been placed for machinery in the various Niagara Falls installations. Such action on the part of the Union Carbide Company is recognition of the success that has been achieved by the contractors in this instance in the design and manufacture of the particular form of apparatus called for in this installation. In the manufacture of calcium carbide, a product, the consumption of which has assumed tremendous proportions, the electric current is an essential element of the manufacturing system. Indeed, calcium carbide is formed as the result of chemical action taking place when the fundamental elements of the carbide are introduced into the electric arc. All electric current used by the Carbide Company for this purpose is transmitted from the great generating station of the Niagara Power Company at a high electrical pressure. Before it can be applied in the Carbide furnaces, this electric current must be reduced in pressure to 110 volts. The transformers, as they are termed, which accomplish this reduction of pressure, constitute the apparatus which is attracting so much engineering interest. Heretofore the largest static transformer in practical service has been a single unit of 1,200 horse power output. This transformer was considered an enormous one and at the time of its manufacture created great interest. The new units, however, which the Carbide Company has installed are of 2,000 horse power output each, and are seven in number. Nothing of the kind has been heretofore heard of in either foreign or American Engineering practice. Much skepticism was expressed as to the ability of the Company securing the contract to accomplish the results guaranteed. One well known foreign engineer who has followed American practice very closely and been greatly interested therein, even went so far as to say that the temerity of the manufacturers astounded him. Every

ONE OF THE SEVEN 2000 H.P. ELECTRICAL TRANSFORMERS BUILT FOR THE UNION CALCIUM CARBIDE CO., NIAGARA FALLS, BY THE WAGNER ELECTRIC MANUFACTURING CO., ST. LOUIS, MO.

claim of the builders, however, and every argument advanced by them in advocating the construction of such large units has been verified by the complete success of the apparatus so far delivered and installed. The first of these great units was installed about four months ago and has been carrying continuously since that time its full load with most eminently satisfactory results in all respects. We produce above an illustration of this apparatus as it appears in actual service. In outward appearance it is nothing more than a great iron shell. Inside however, is the transformer proper, made up of heavy windings of pure

copper, grouped so as to accomplish the results desired. Surrounding these great copper windings is a large copper cooling coil through which a constant stream of running water is passing. This cooling coil together with the transformer proper is completely immersed in oil. This oil circulates freely through the windings of the transformer and carries away by both conduction and convection the heat losses arising in the transformer. This heat reaches the cooling coil by the circulation of the oil and is transferred to the running water in the cooling coil and thus carried out of the transformer entirely. Each of these units has the enormous weight of 40,000 pounds in complete form. As one stands beside the apparatus, it seems incomprehensible that so silent an agent should be performing work of such tremendous magnitude.

The builders of this apparatus are the Wagner Electric Manufacturing Company of St. Louis, a Company which has now attained a world-wide reputation for the manufacture of this form of electrical machinery, and also several other lines of apparatus largely used in the alternating current field. This progressive Company of the West entered the lists against the two great companies of the East who have heretofore monopolized the business at Niagara, and in successfully carrying out their contract, have set a pace in the electrical industry which means an immediate innovation of new ideas the world over, in this particular form of electrical machinery. To the Wagner Company is now due the credit of having, not only built the largest units ever constructed in static transformers, but also the praise for introducing the highest voltage transformers in large units that have ever been placed in practical service. The latter apparatus was installed on the circuits of the Telluride Power Transmission Company at Provo, Utah, and has been most successfully operated about two years on a line pressure of 40,000 volts. The units in this service are of 300 and less kilowatt capacity each.

The development of the Wagner Electric Manufacturing Company has been one of the marvels of this electrical era. Seven years ago this Company was organized with a capital stock of $25,000.00 to manufacture one or two small electrical specialties St. Louis as a manufacturing center, and the rapid opening up of the electrical field resulted in an expansion of this Company into one with very large capitalization, until now the industry ranks as the leading one of the West in its particular electrical line. The Company has branched out until its output is now being shipped to all sections of the world, and wherever it is sent is recognized for its excellence. Indeed, the aim of this Company has been to build nothing but high grade apparatus, and the present influential position occupied by it in the electrical field is entirely the result of this broad gauge policy. The Company does not pretend to go into all fields of electrical machinery, but confines itself strictly to a number of lines of product of which Static Transformers head the list, with a new form of Single Phase Alternating Current Motor, Indicating Switchboard Instruments, Direct Coupled Ventilating Fans, Storage Battery Charging Outfits, Switchboard Work and Direct Current Motors and Dynamos, constituting the other chief products.

An immediate consequence of the success achieved in the equipment of the plant of the Union Carbide Company at Niagara Falls, has been the award to the Wagner Company, of the contract for the similar equipment of the great Canadian Carbide Plant now building at Ottawa, Canada, in which will be installed at the start, twenty units of 150 kilowatt output each.

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